Tracking cosmic ray variation due to solar effect by using Neutron monitor measurement

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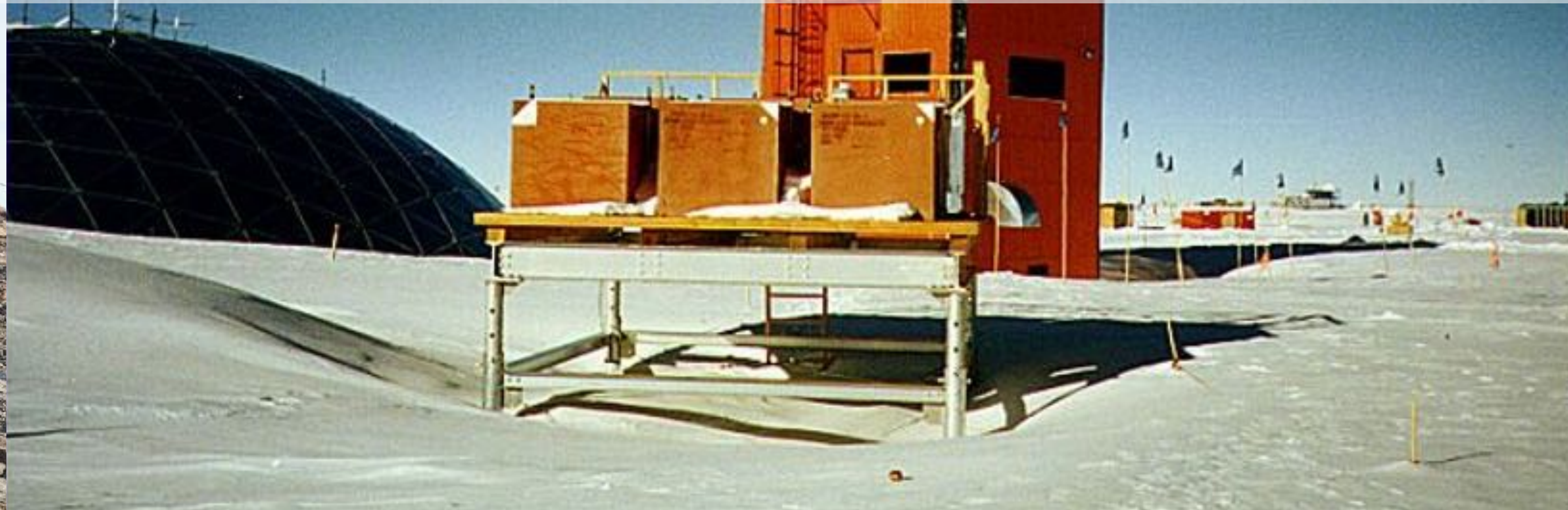
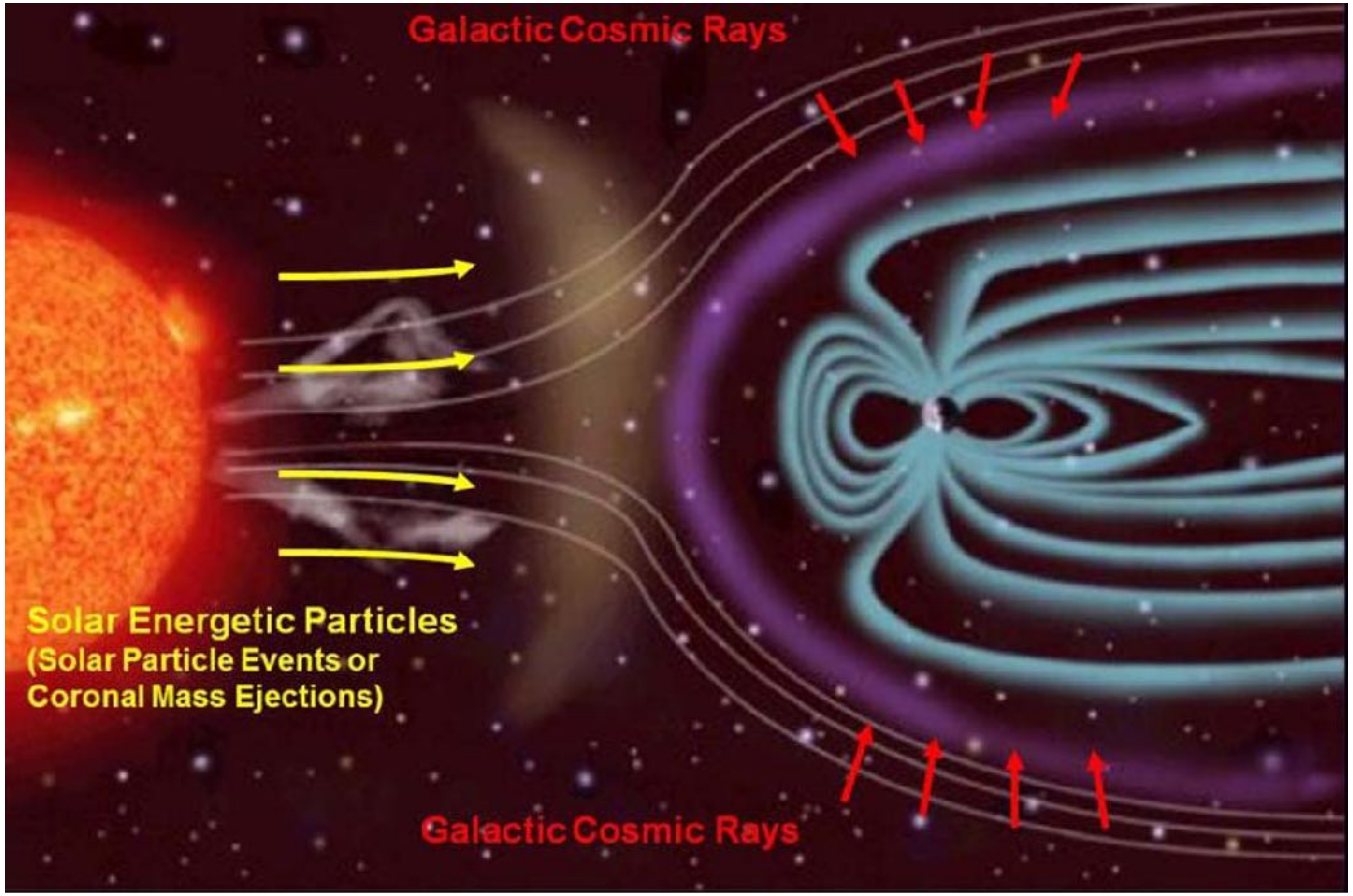
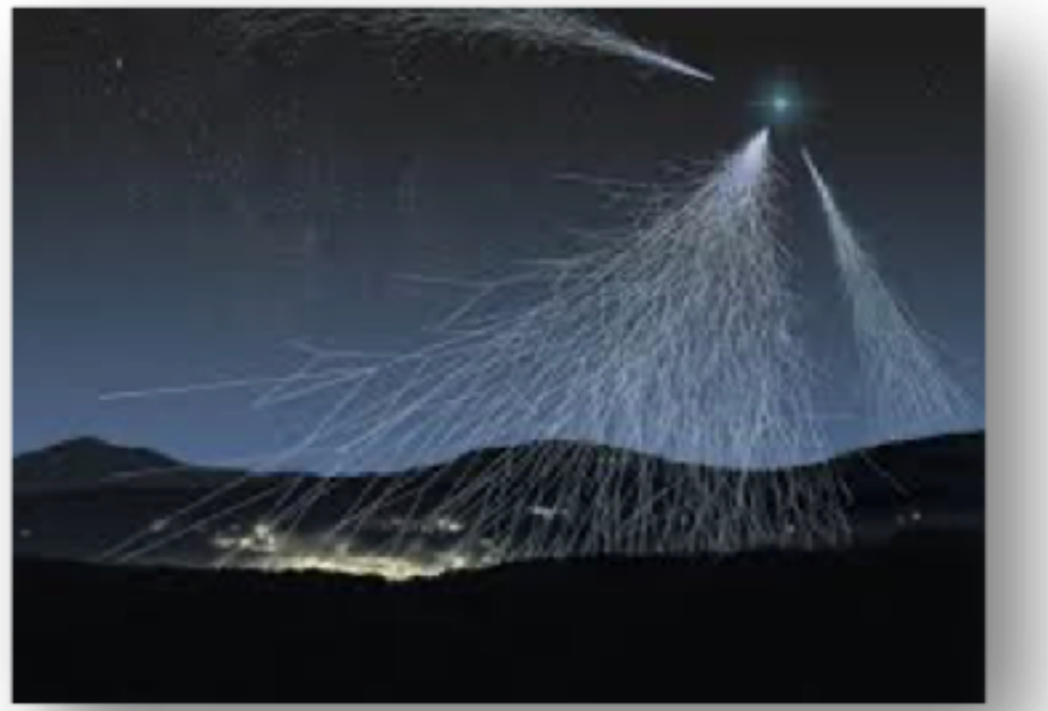


Cosmic rays





•Energetic particles or gamma rays from outer space such p, ^4He, e^+, e^-, ions, etc.
•Ordinary matter accelerated to high energies
•Key cause of biological mutations
•Sources of cosmic rays (energetic particles)
•Solar Energetic Particles (SEP) are the high energy cosmic ray from the Sun.
•Galactic Cosmic Rays (GCR) are the high energetic particles that came from a source outside the solar system.

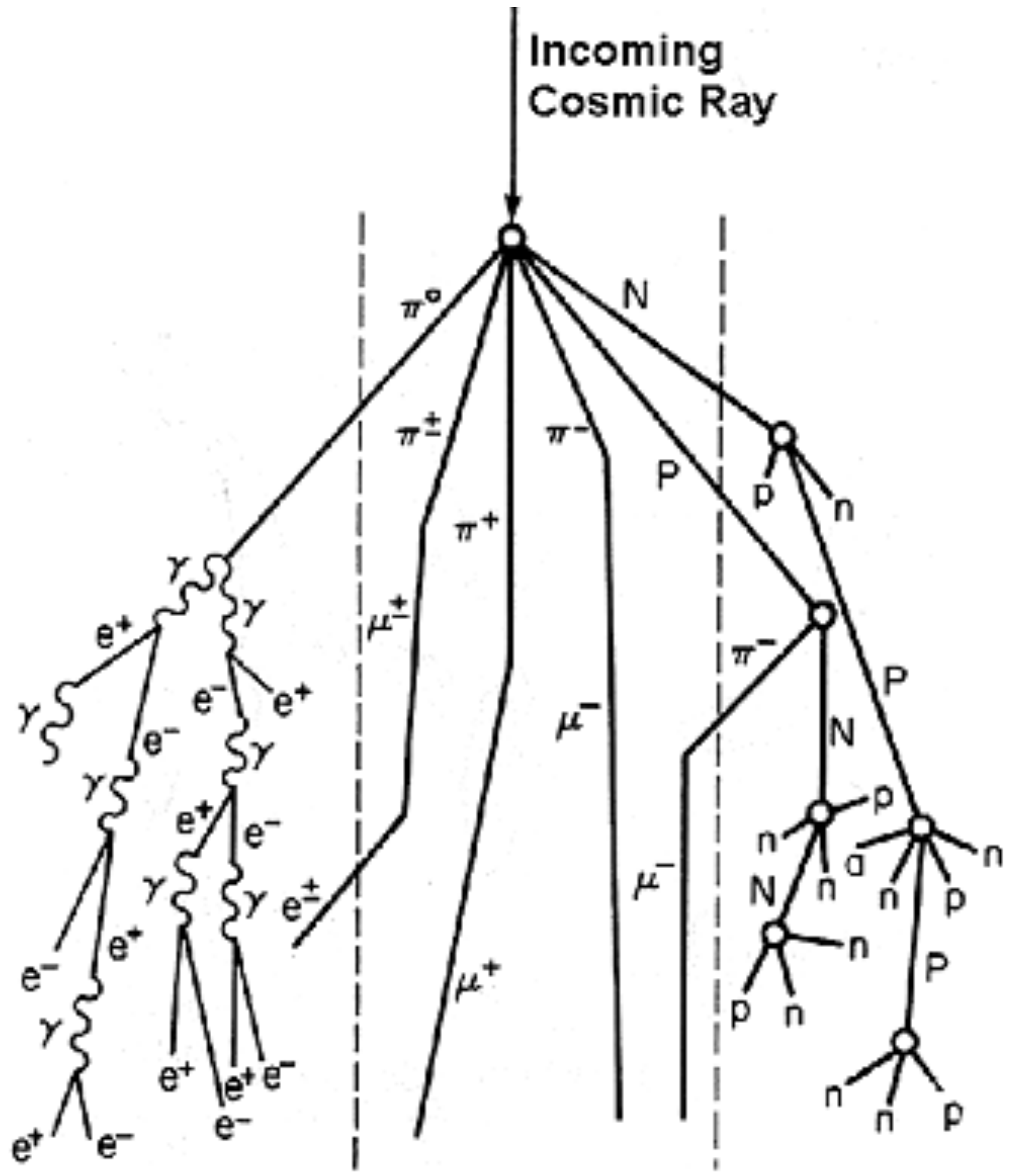
https://en.wikipedia.org/wiki/Cosmic_Ray

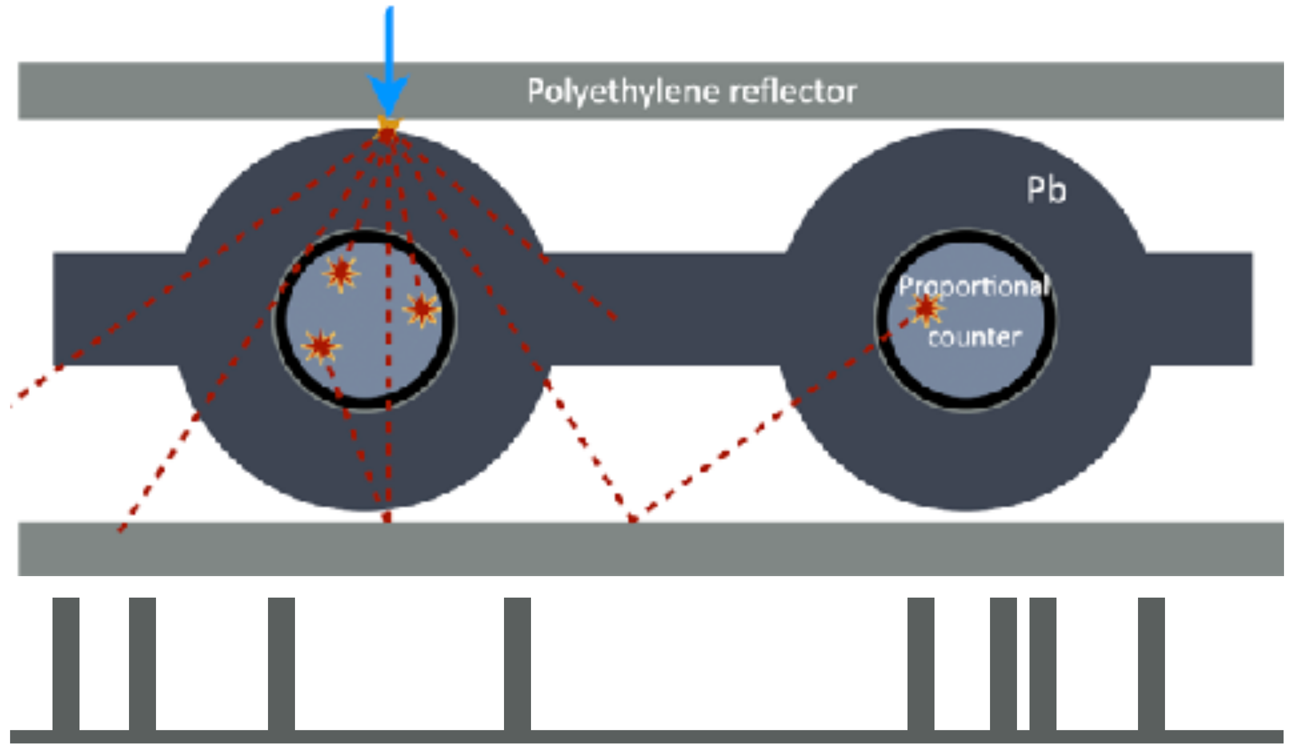
Neutron Monitor & Time-delay Measurement

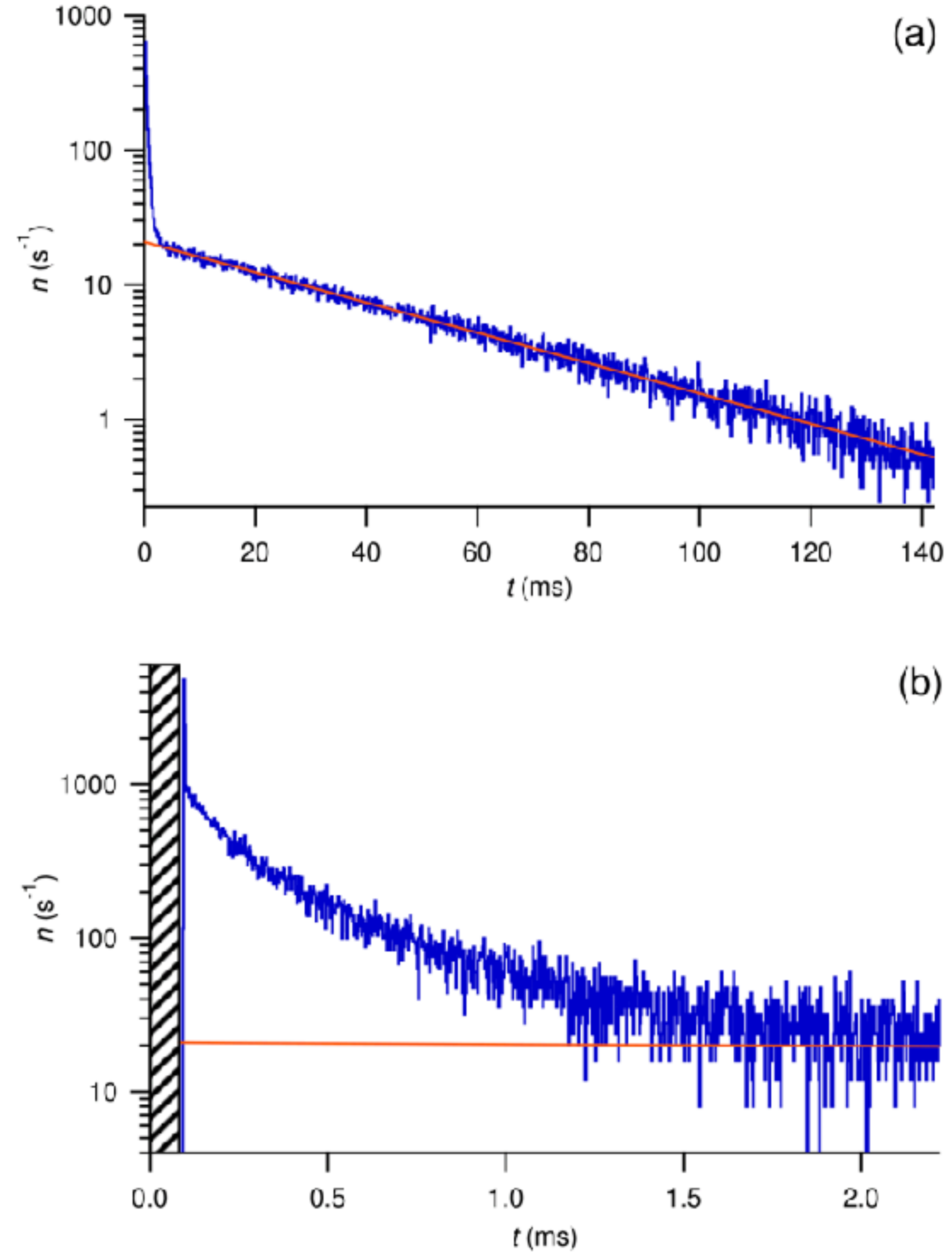
- The electronics records time delays between successive neutron counts, on count to the next count
- Long time delays: counts from independent atmospheric neutrons, unrelated events
- Short time delays: mostly from neutrons produced from the same Pb nucleus
- Ruffolo et al., 2016 calculated ***L*** from the time delays histograms
- ***L*** from histograms of time delay related to cosmic ray spectral index.

$$L = \frac{1 - e^{-\alpha t_o}}{\alpha e^{\alpha t_d}} A$$

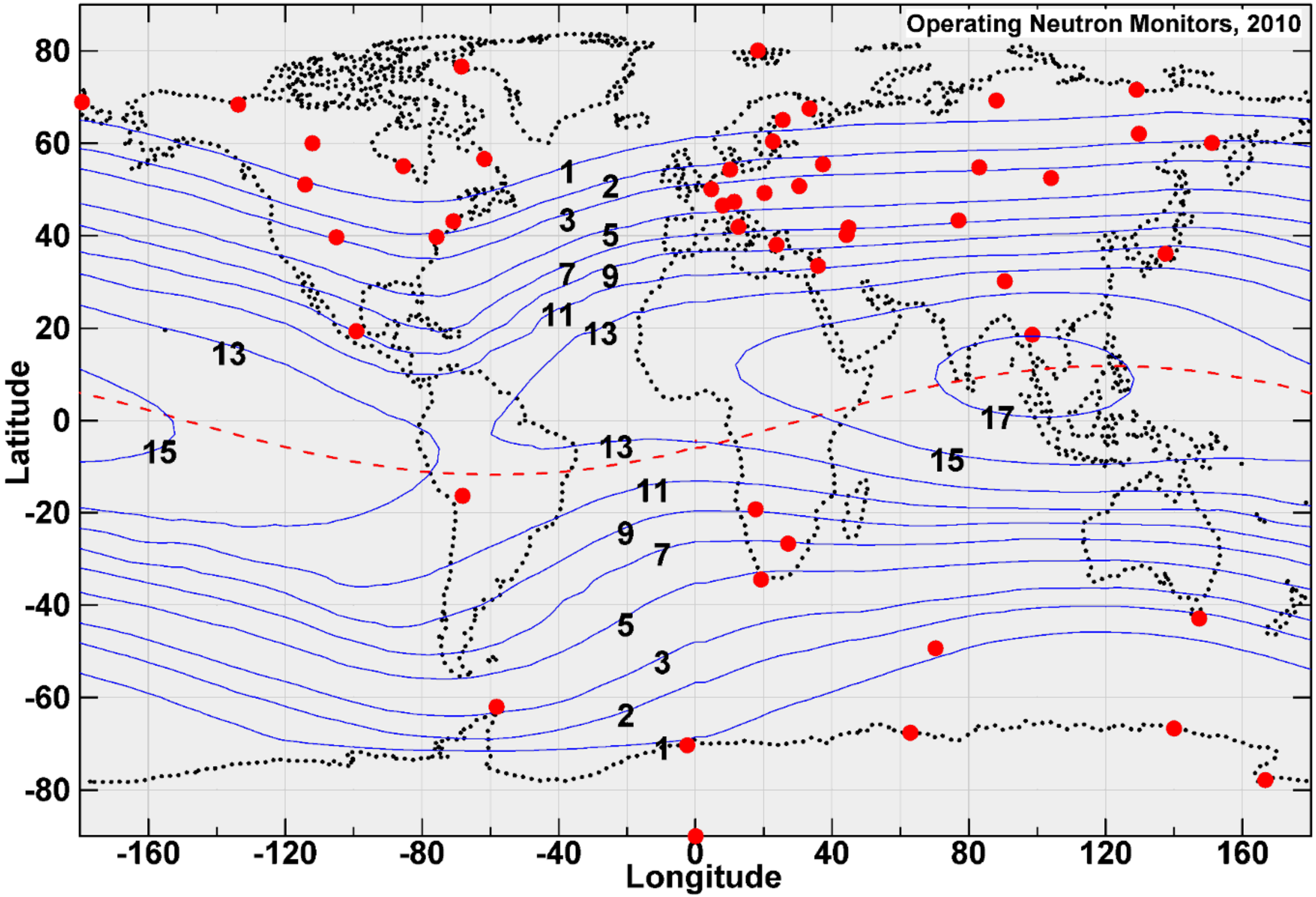
where α and *A* are the parameters from the long time histogram fitted to the exponential tail $Ae^{-\alpha t}$ of time delay t, t_o is the overflow time in the electronic system, and t_d is the effective electronic dead time







[Ruffolo et al., 2016]


Operating Neutron Monitors, 2010
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-160
-120
-80
-40
0
40
80
120
160
1
2
3
5
7
9
11
13
15
17

Normalization and Correction Leader Fraction

Correction for atmospheric pressure and water vapor

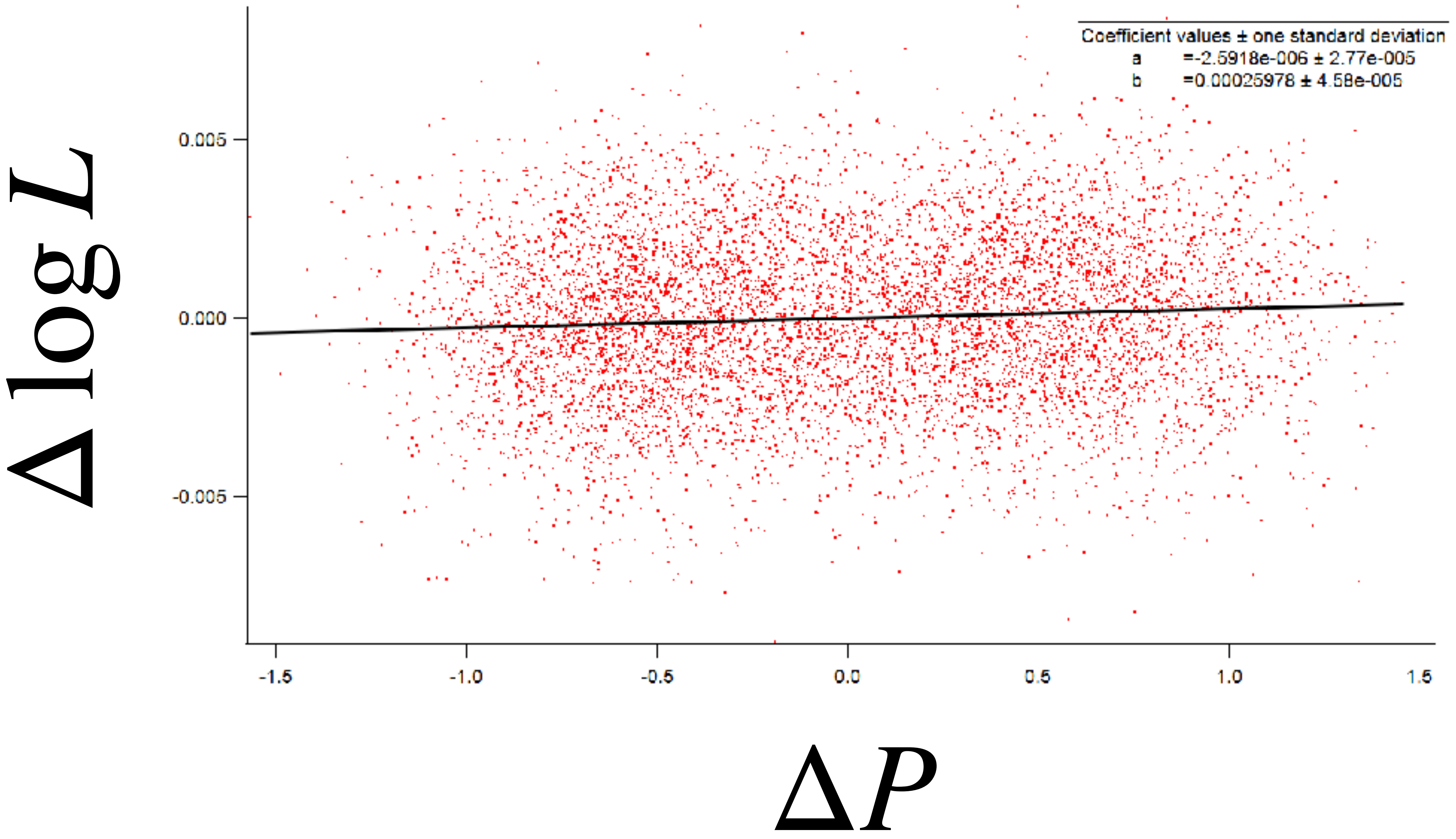
Atmospheric pressure correction

To remove the effect of the atmospheric depth, we fit $\Delta \ln L$ vs. ΔP with a linear model.

The parameter b of that linear fit was defined as a coefficient of pressure correction.

$$L_{\text{Pcorr}} = L_{\text{Uncorr}} \exp[-b(P - P_0)]$$

P_0=563 mmHg is the reference pressure at Doi Inthanon.



Normalization and Correction Leader Fraction

Correction for atmospheric pressure and water vapor

Water vapor pressure: E_w

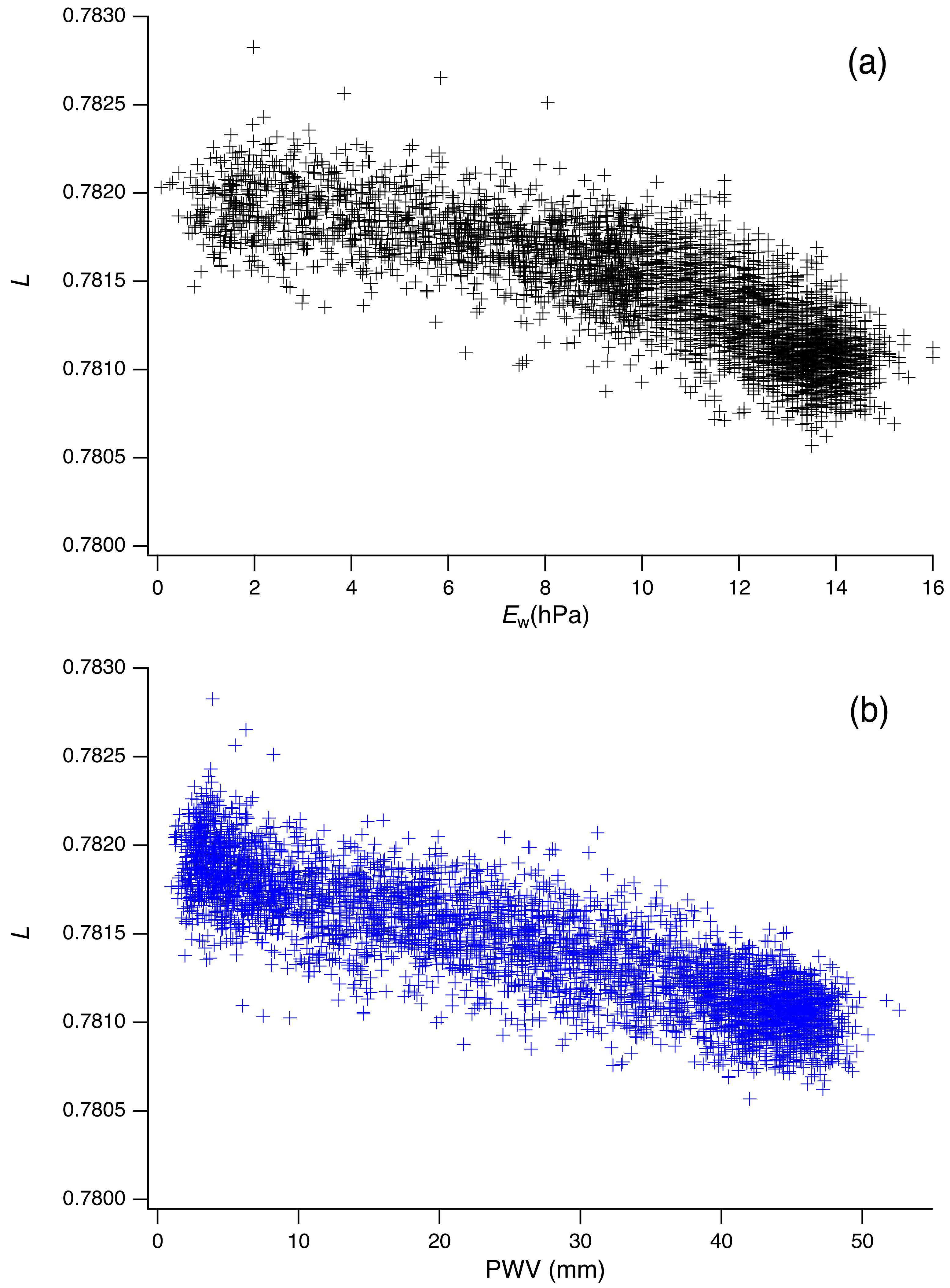
$$E_w = (6.113\ \text{hPa})\frac{RH}{100}\exp\left(\frac{17.62T}{T+243.12}\right)$$

Precipitable water vapor: PWV

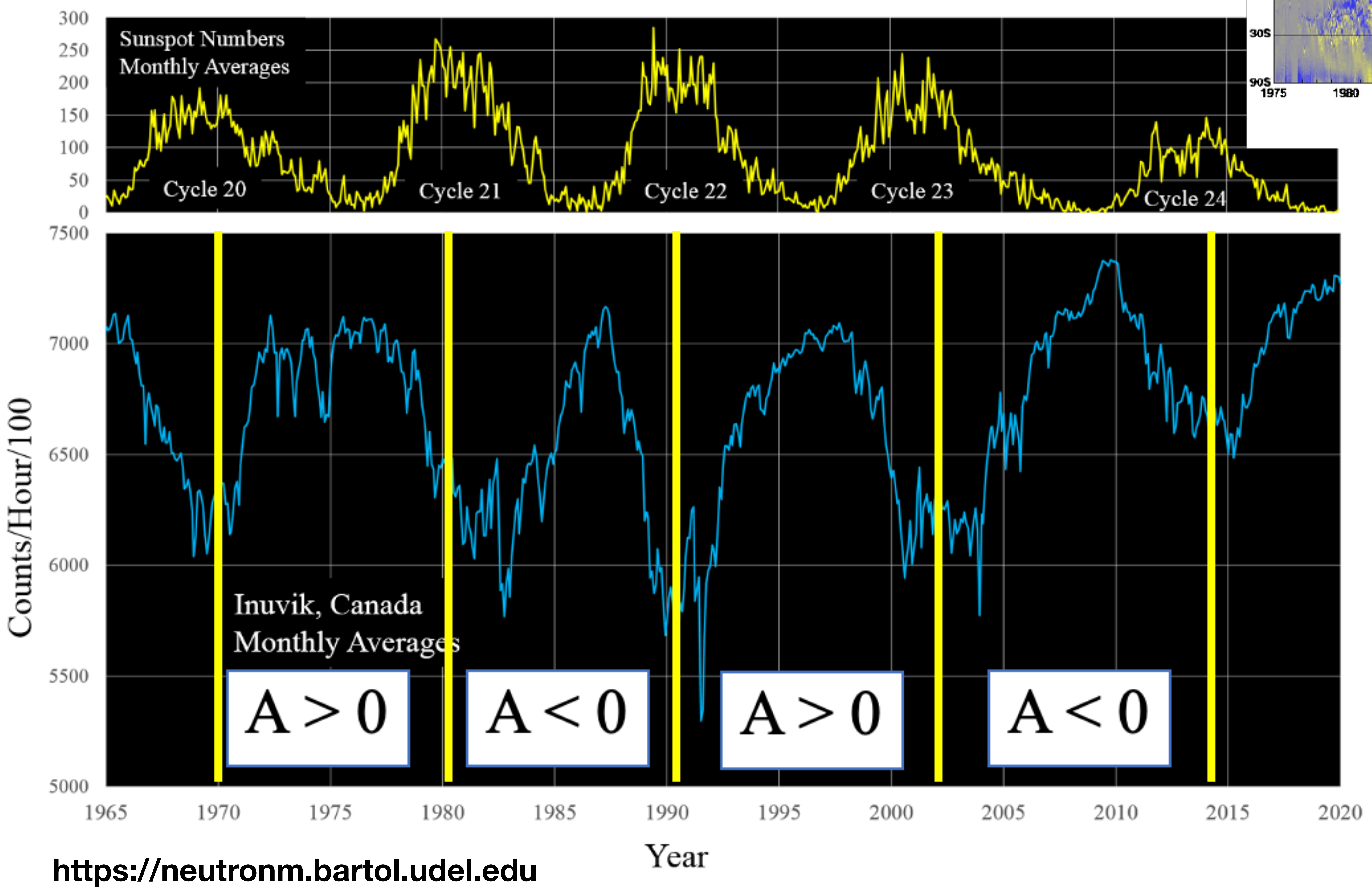
The vertical integral of the absolute vapor mass density which yields the column water per m²

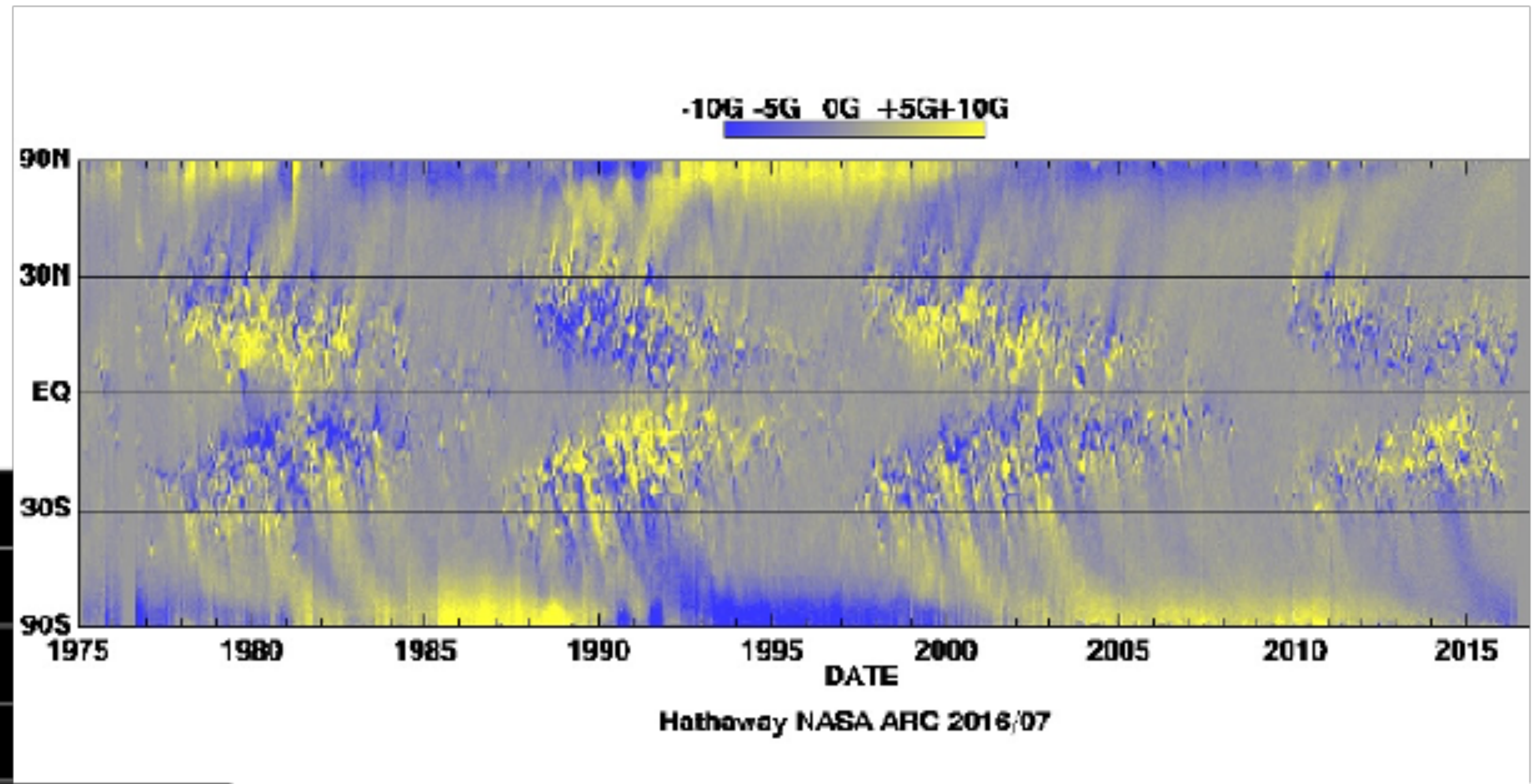
$$\text{IWV} = \int_0^P \frac{q}{g}dP \quad \Rightarrow \quad \text{PWV} = \frac{\text{IWV}}{\rho_w}$$

where $q = \frac{E_w}{p}$



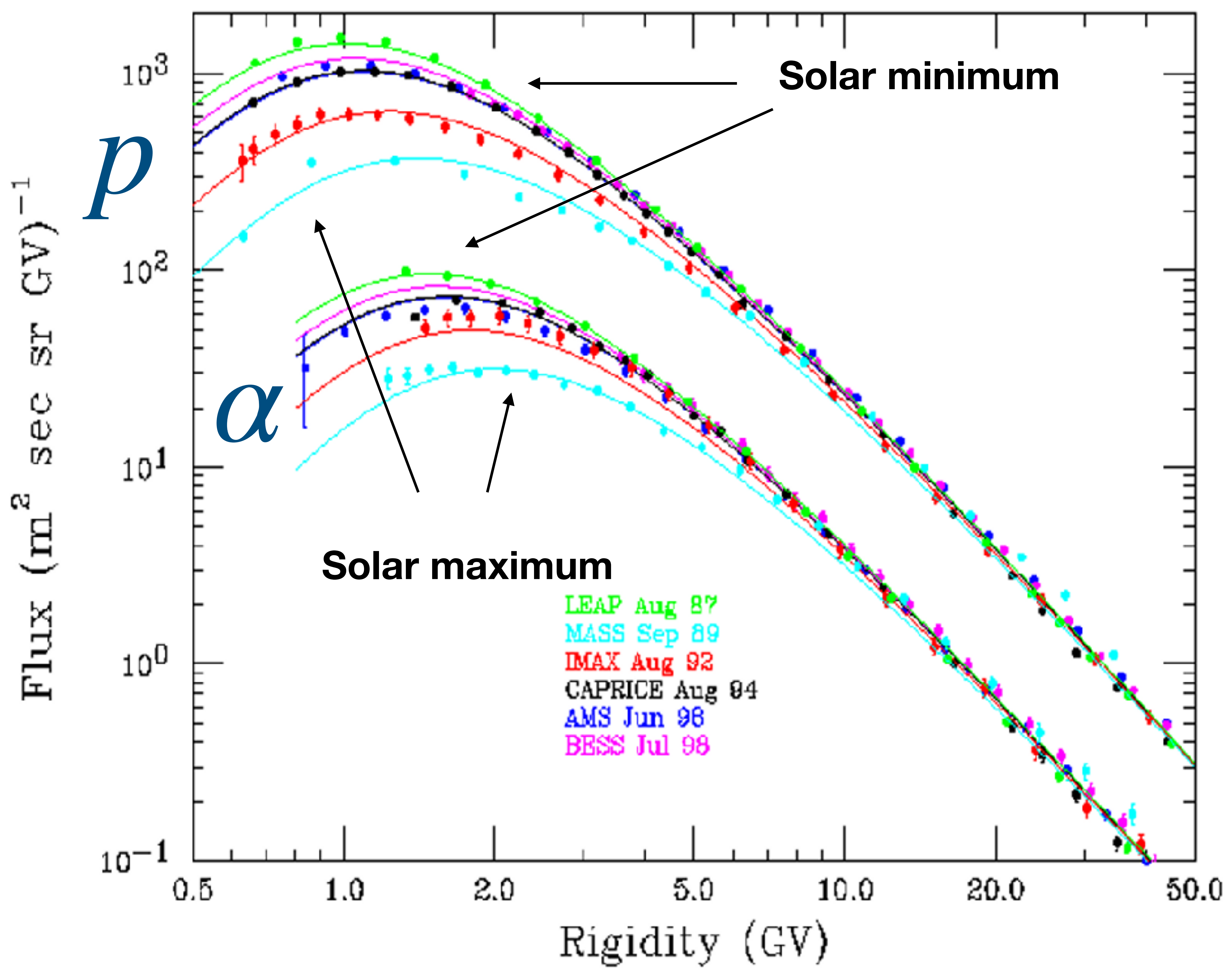
Solar Modulation



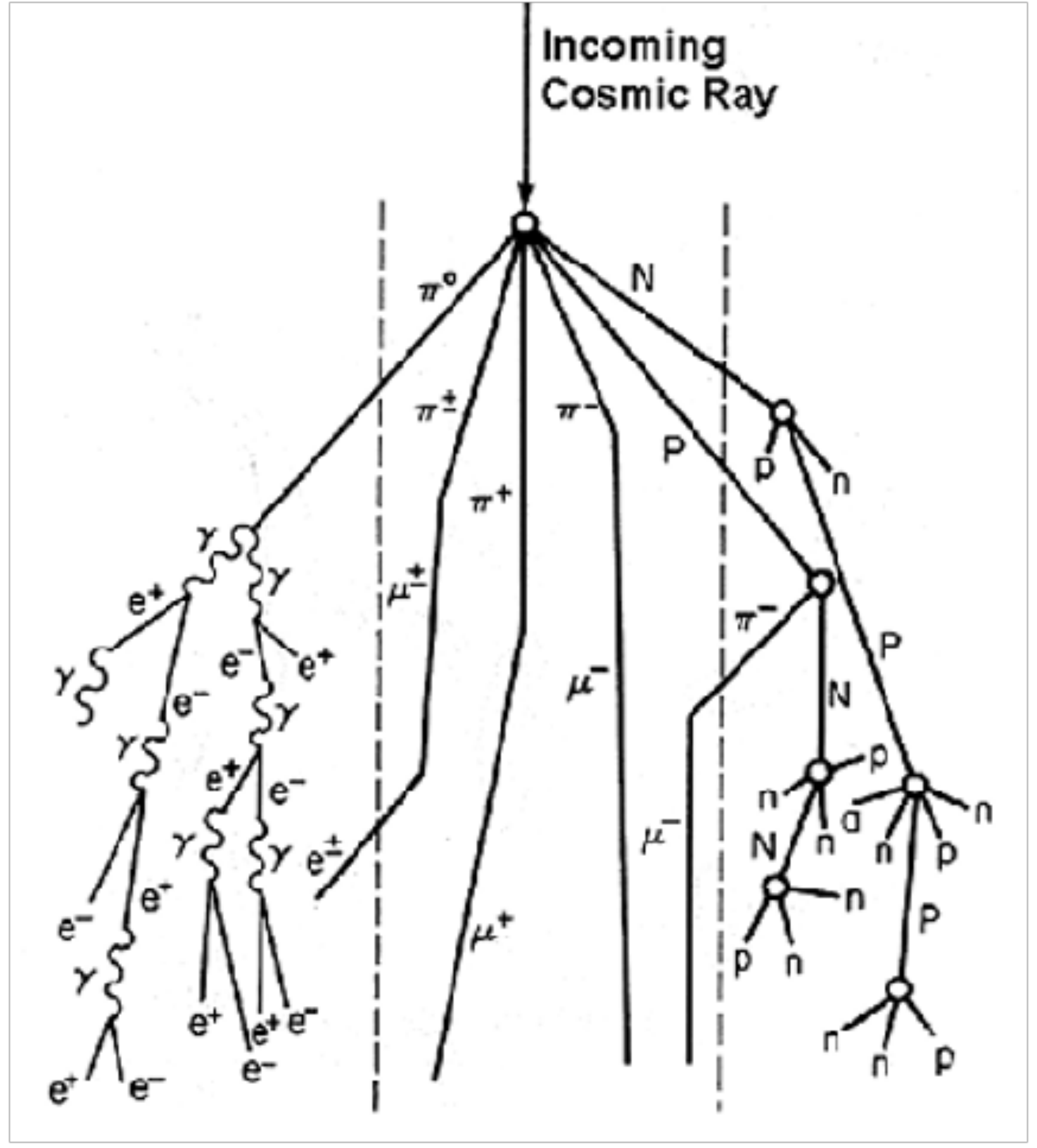


https://neutronm.bartol.udel.edu

The energy (or rigidity) spectrum of galactic cosmic rays varies with the solar cycle.



[Clem et al. 2003]



More energetic primary
More energetic secondary

↓

More neutrons in monitor

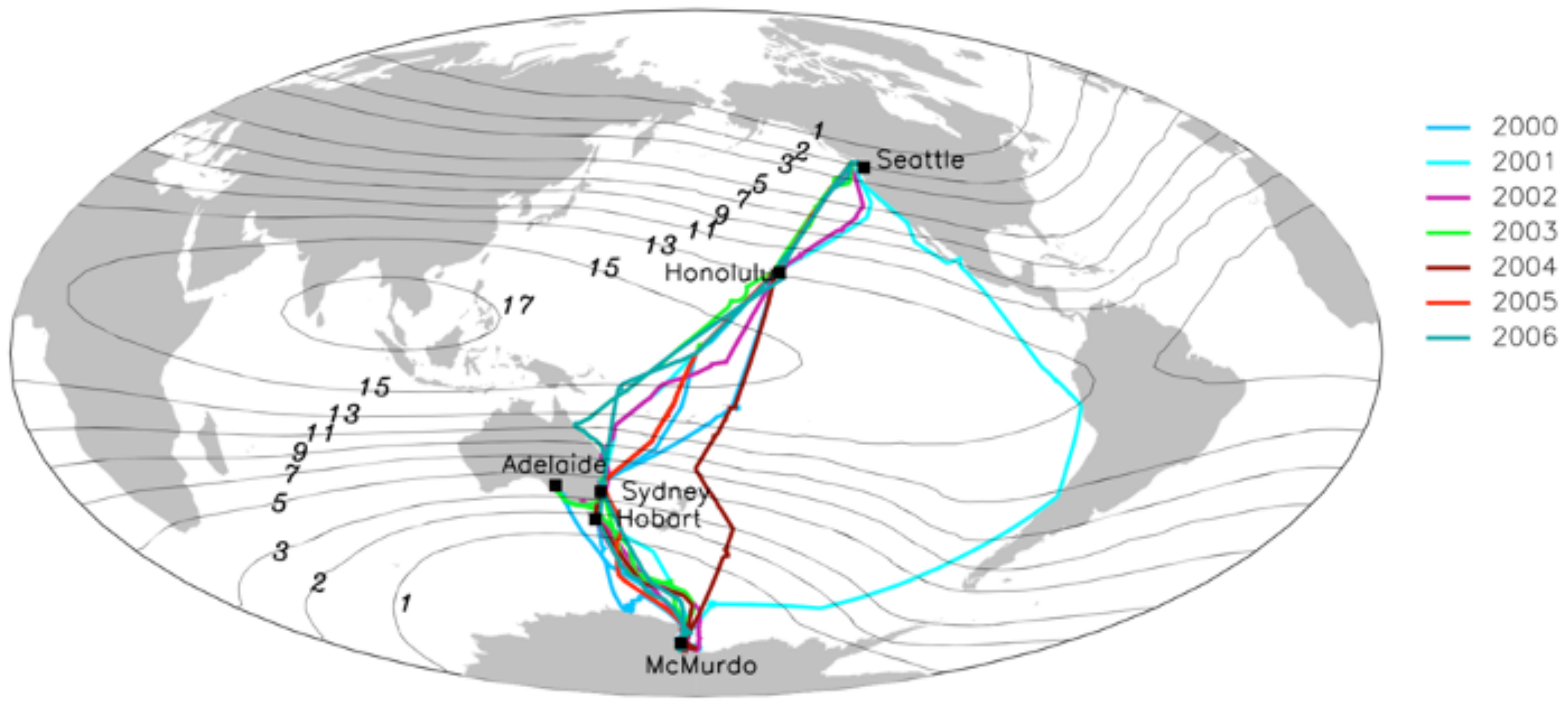
↓

Higher multiplicity

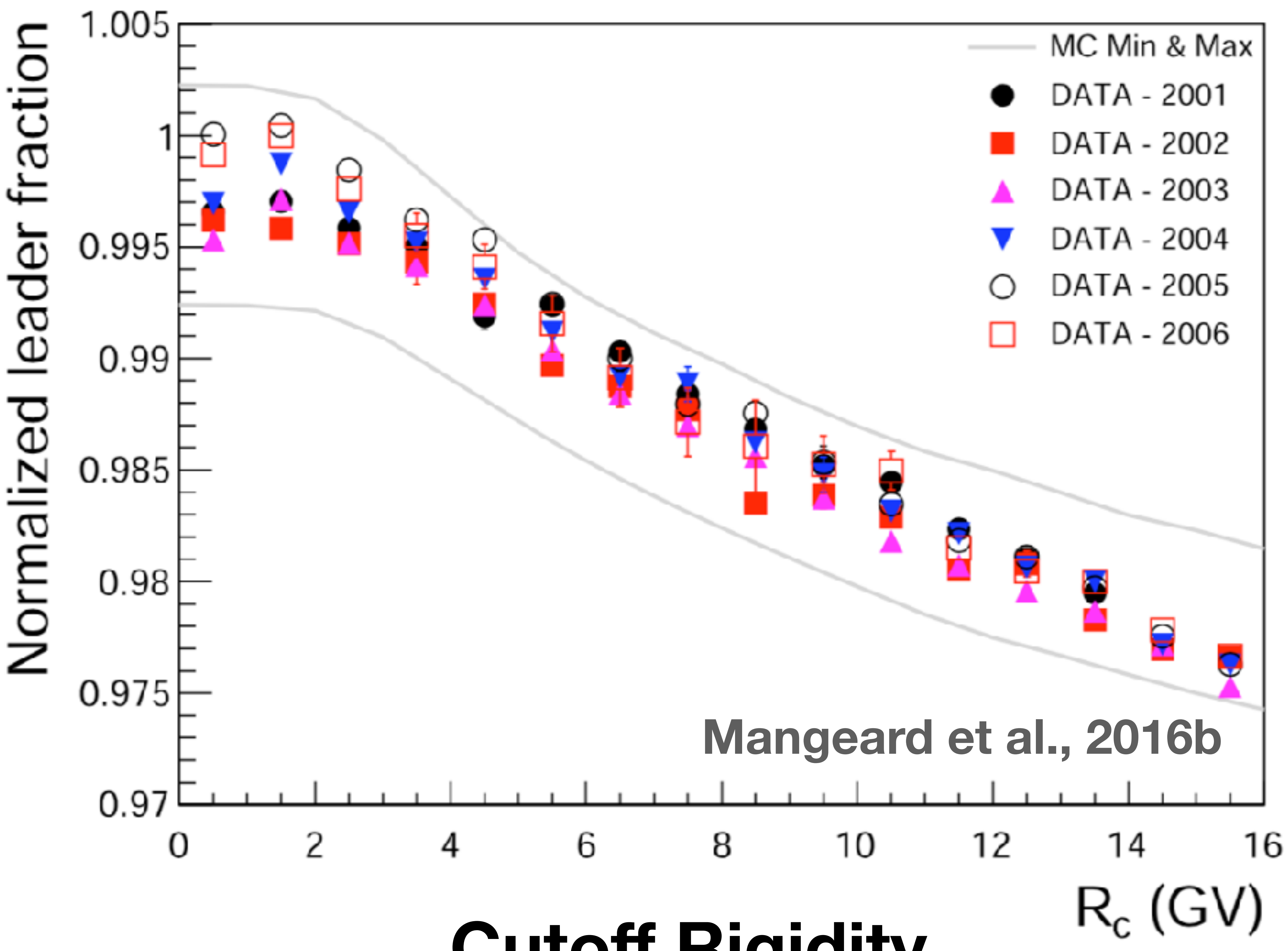
L = "leader fraction"
(inverse multiplicity)

Leader fraction & cosmic ray spectrum

... from a ship-borne latitude surveys 2000 - 2007



Mangeard et al., 2016b



Cutoff Rigidity

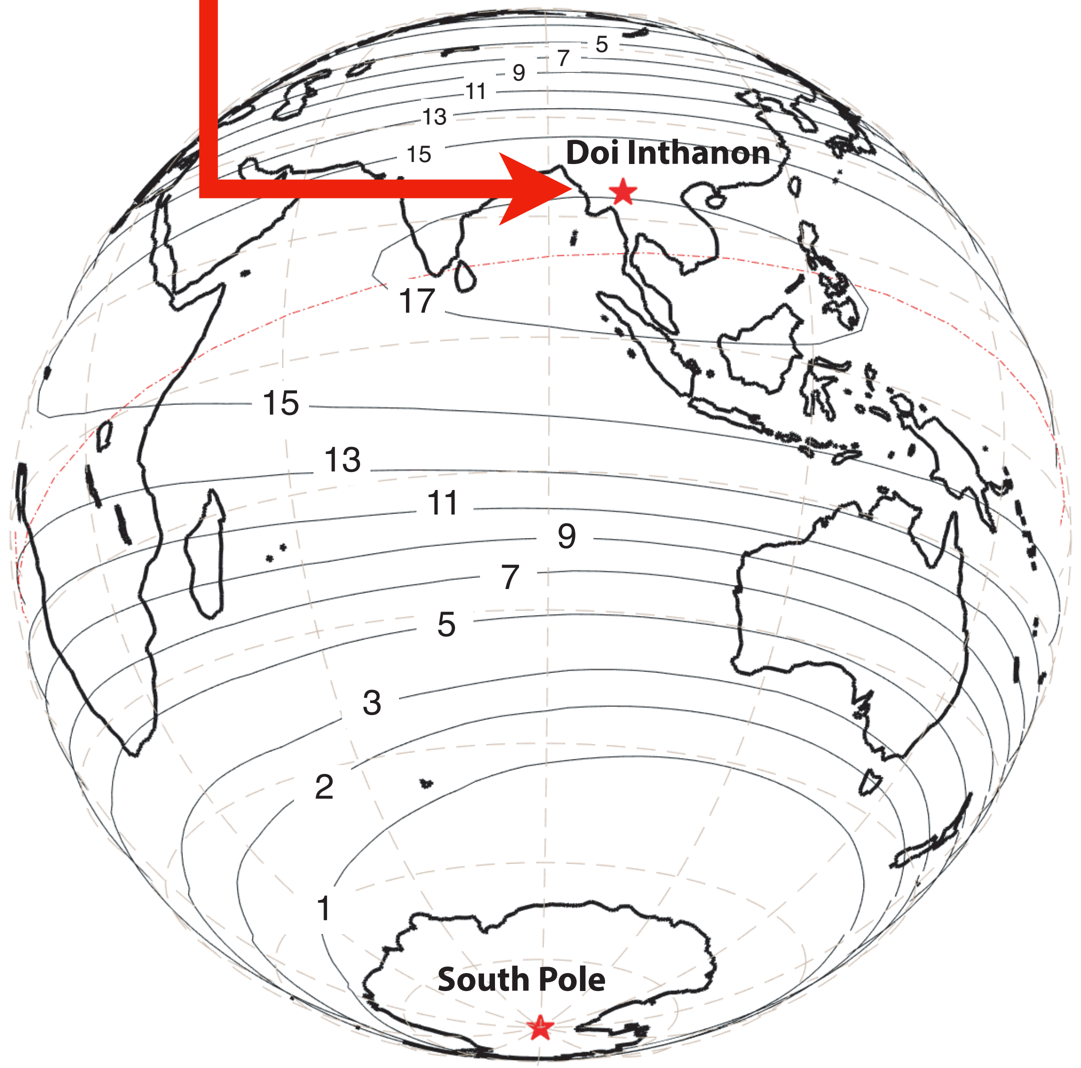
Forbush Decreases observed by NMs

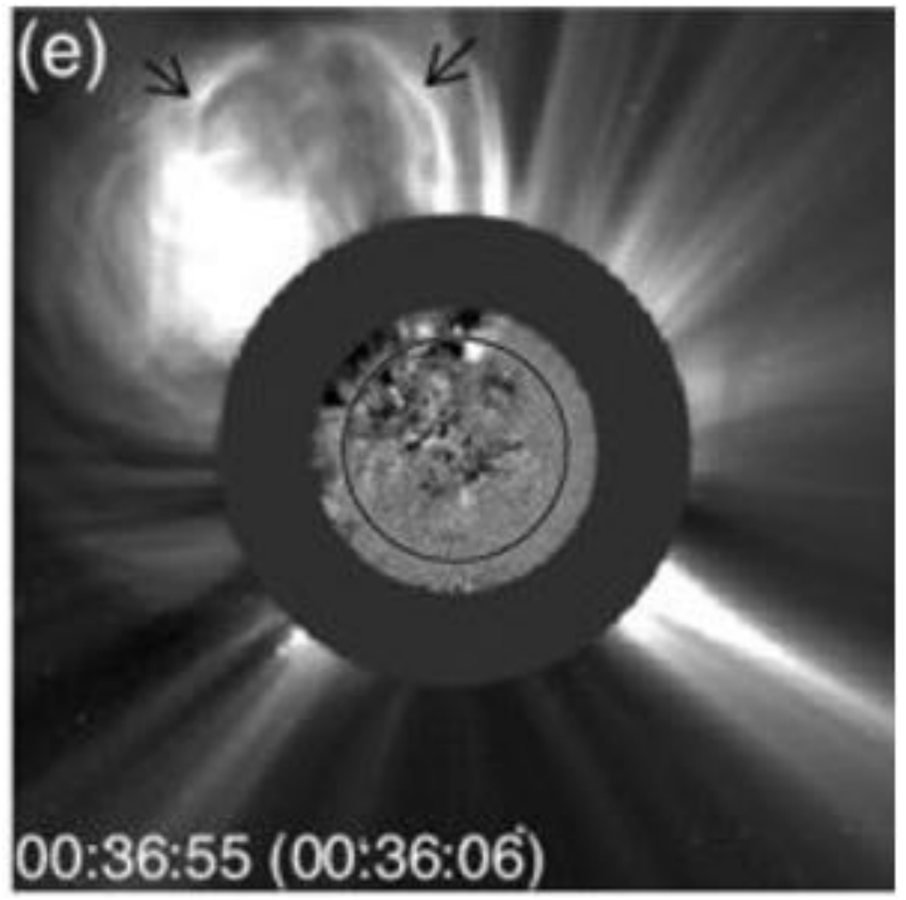
The amplitude of decrease depends on the geomagnetic cutoff rigidity.

Cosmic rays of lower rigidity are more strongly affected by shocks and CMEs

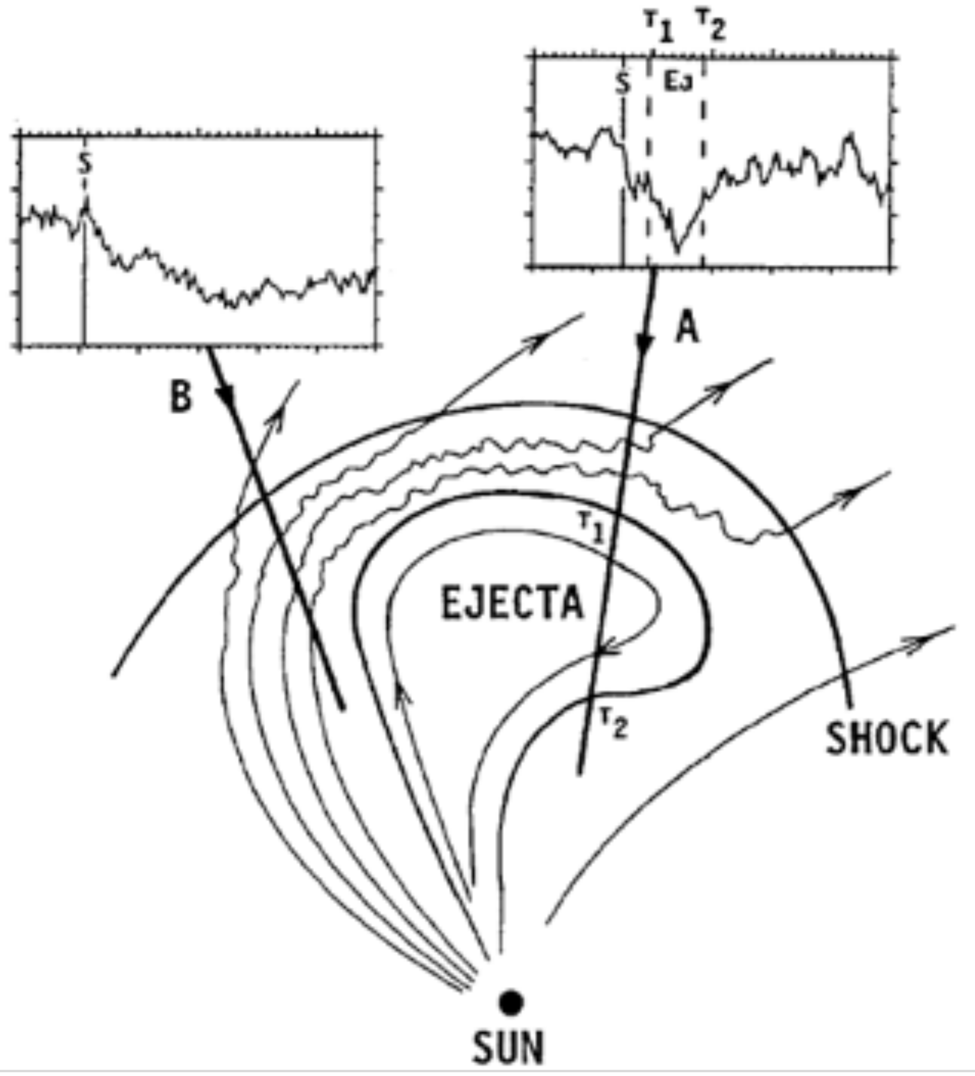
[Ruffolo et al. 2016]

Princess Sirindhorn Neutron Monitor (PSNM) at Doi Inthanon, Thailand with the world's highest vertical cutoff rigidity ~16.7 GV

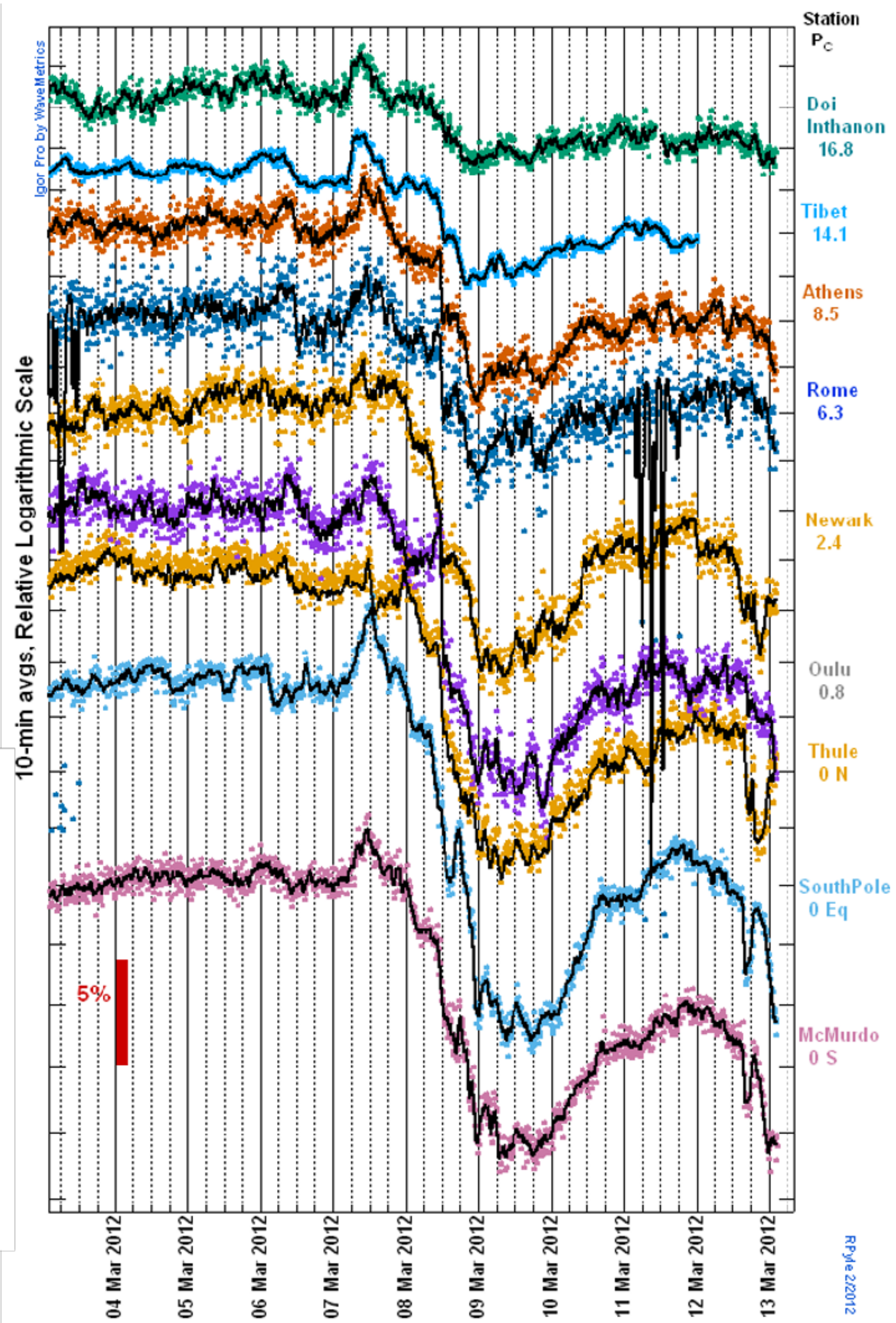


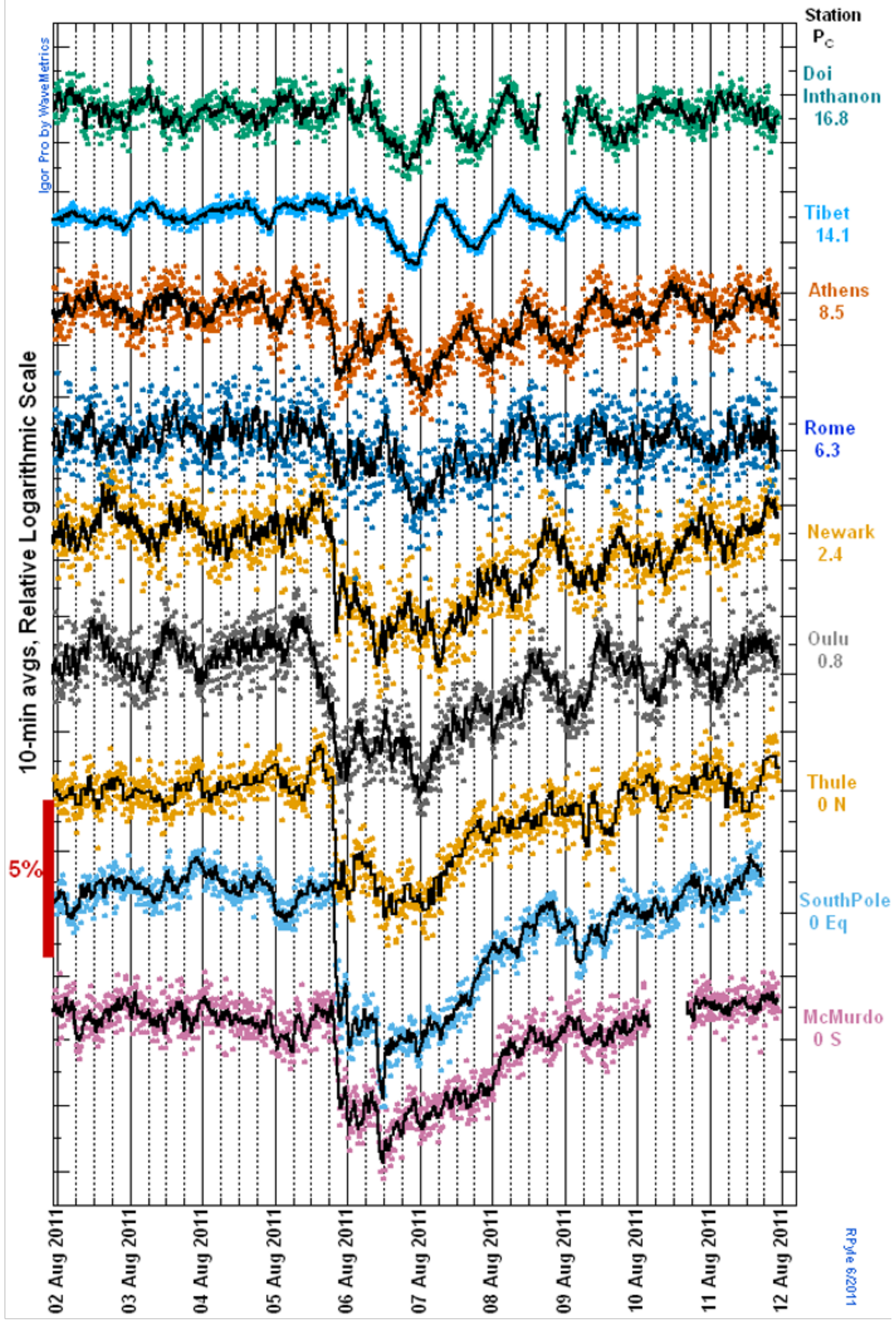


CME of 2012 Mar 7 (Kwon et al. 2014)



[Cane 2000]



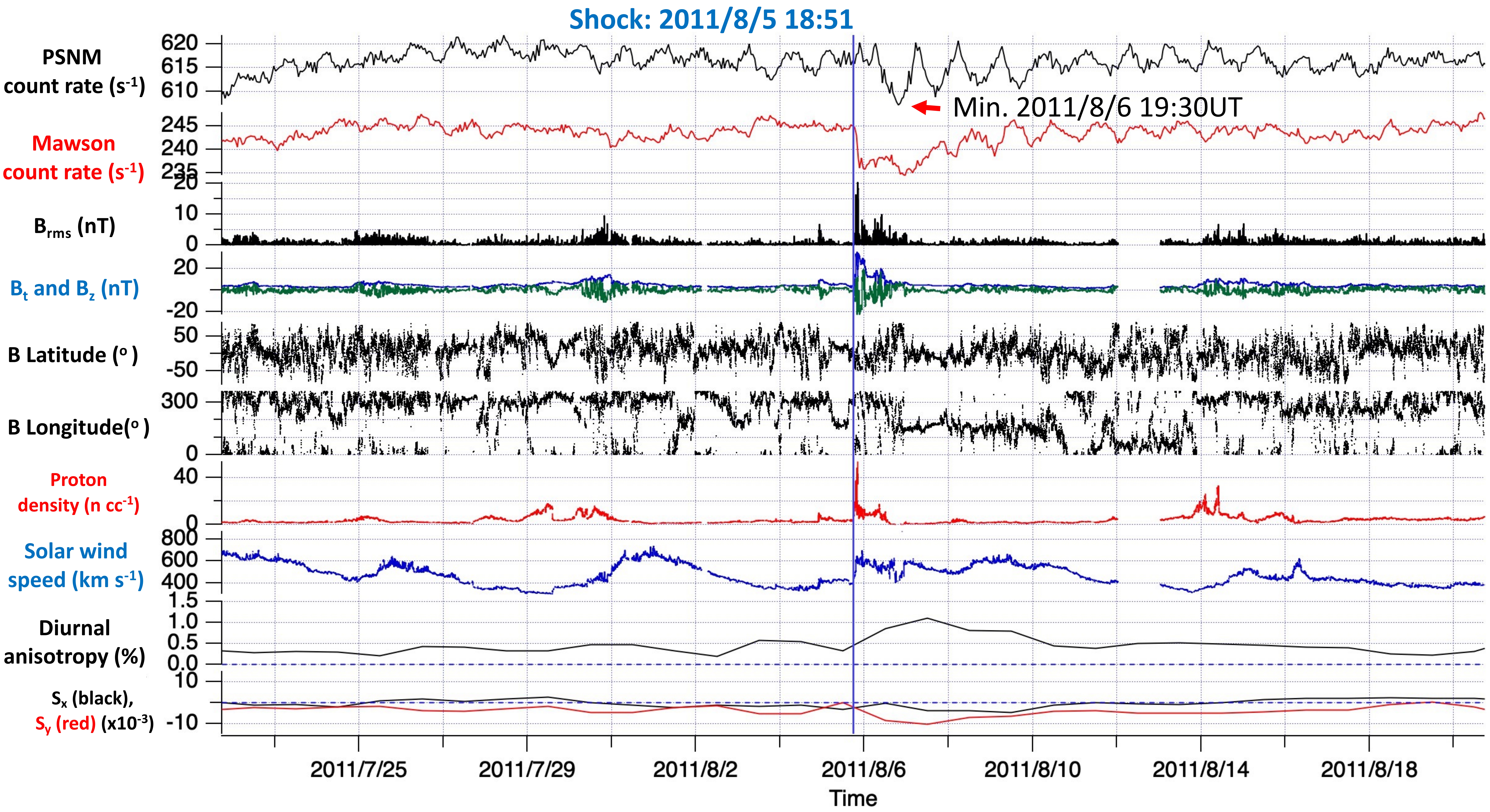


Diurnal Dips

- NMs have observed diurnal variations of the GCR flux due to the Earth's rotation.
- The viewing direction of an NM sweeps across the sky as Earth rotates.
- When NMs at lower cutoff rigidity observe an FD, PSNM does not always observe a standard FD with rapid decrease and gradual recovery over several days.
- Instead, PSNM often sees repeated dips, only at certain times of day, corresponding to certain directions in space …

… while the GCR flux from other directions is nearly unchanged.

- We call such these "diurnal dip" (DD) events.
- From 2008 to 2019 (Solar Cycle 24), we observed 8 DD and 20 FD events in PSNM data.

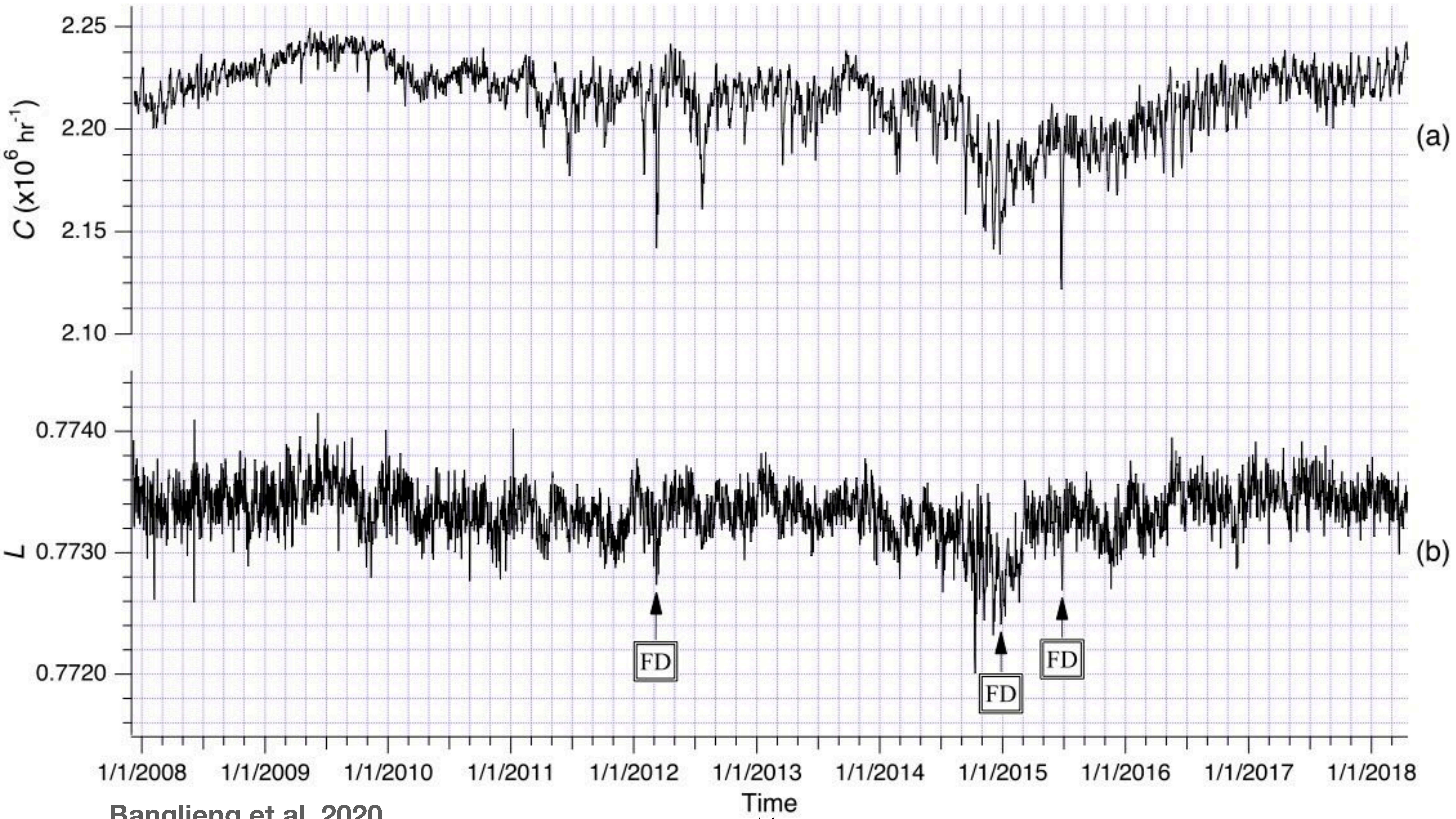


Shock: 2011/8/5 18:51
PSNM count rate (s-1)
620
615
610
Min. 2011/8/6 19:30UT
Mawson count rate (s-1)
245
240
235
Brms (nT)
20
10
0
Bt and Bz (nT)
20
-20
B Latitude (o)
50
-50
B Longitude(o)
300
0
Proton density (n cc-1)
40
0
Solar wind speed (km s-1)
800
600
400
Diurnal anisotropy (%)
1.5
1.0
0.5
0.0
Sx (black),
Sy (red) (x10-3)
10
-10
2011/7/25
2011/7/29
2011/8/2
2011/8/6
2011/8/10
2011/8/14
2011/8/18
Time

Diurnal dip observed at PSNM

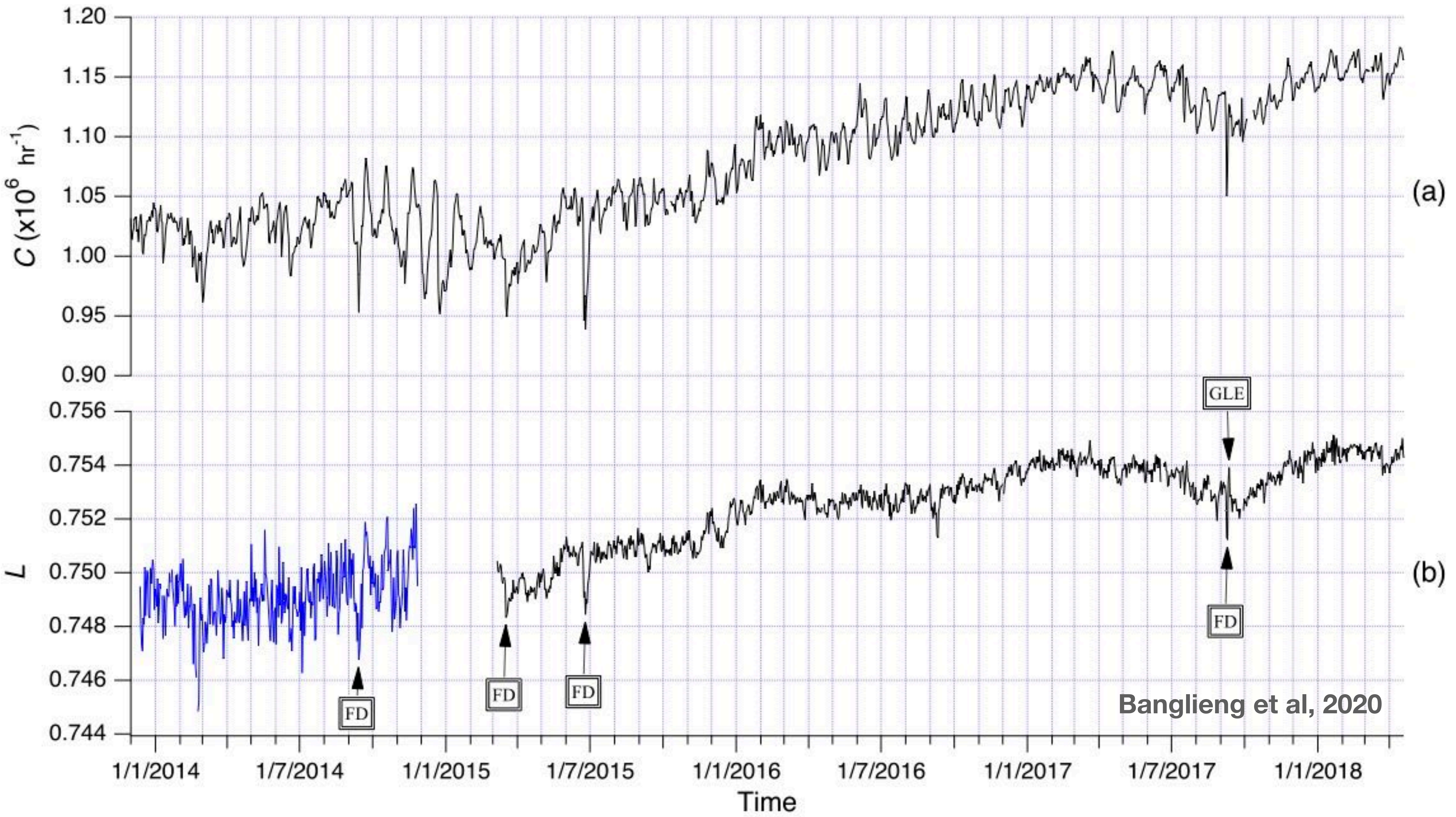
- When CMEs and shocks lead to a Forbush decrease (FD) in the GCR flux as observed at low cutoff rigidity, observations by the Princess Sirindhorn Neutron Monitor (PSNM) at Doi Inthanon, Thailand at cutoff rigidity ~17 GV exhibit either
  1. A weaker FD, usually with faster recovery
  2. A diurnal dip (DD) event, in which the GCR flux is temporarily lower only during certain times of day, corresponding to particle arrival from the dawn sector, or
  3. No noticeable effect.
- We identified 8 DD events and 20 FD events from 2008 through 2019

Leader fraction *L* and count rate *C* at Doi Inthanon, Thailand



Banglieng et al, 2020

Leader fraction *L* and count rate *C* at South Pole



Antarctic NM stations

South Pole Station (SP):

- 1 tube (Dec. 2013)
- 3 tubes (Mar. 2015)

McMurdo Station (MC):

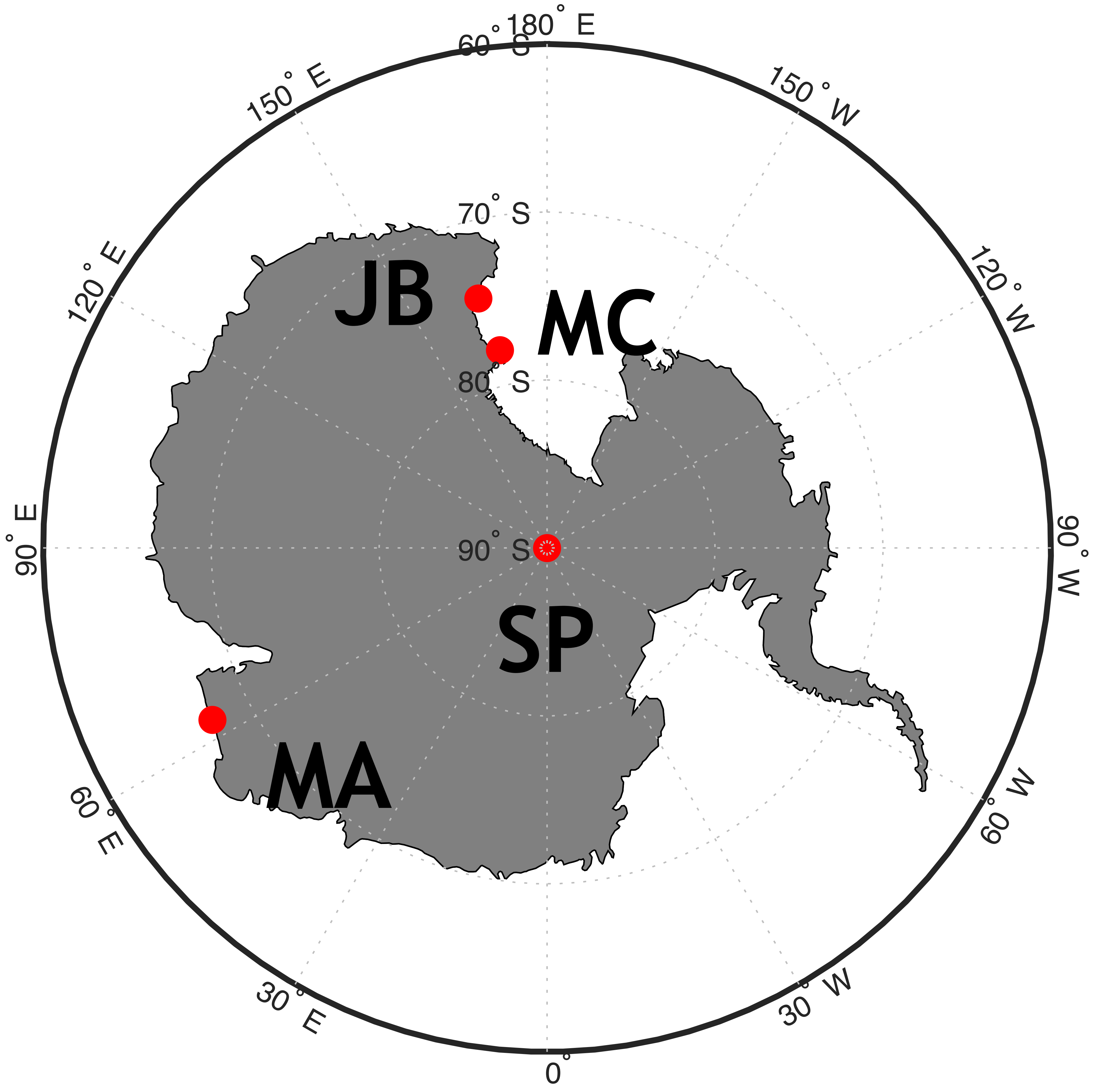
- 11 tubes with 6 tubes special electronics (Dec. 2015 to Jan. 2017)

Jang Bogo Station (JB):

- 6 tubes (Dec 2015 to Jan. 2019)
- 18 tubes with 11 tubes special electronics (Jan. 2019)

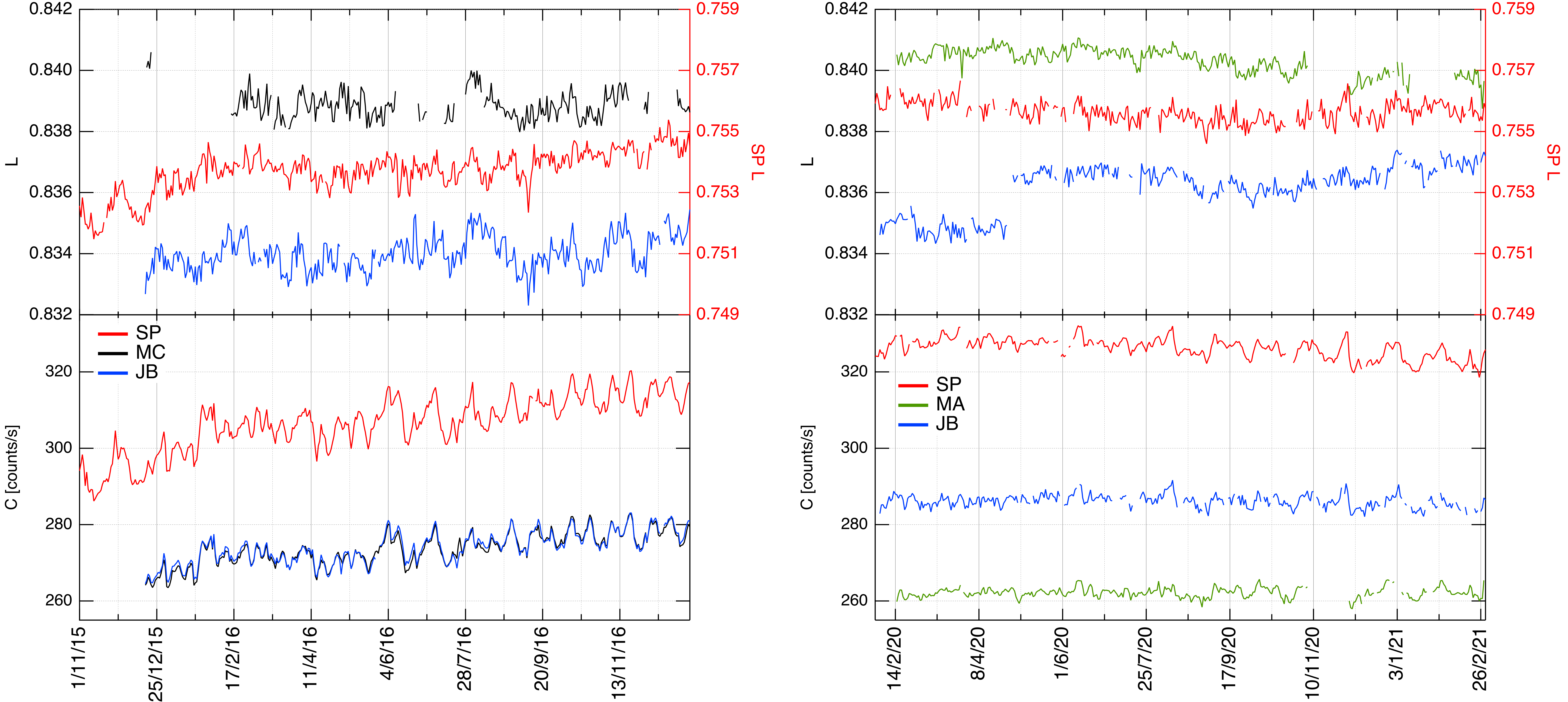
Mawson station (MW):

- 18 tubes (Feb. 2020)

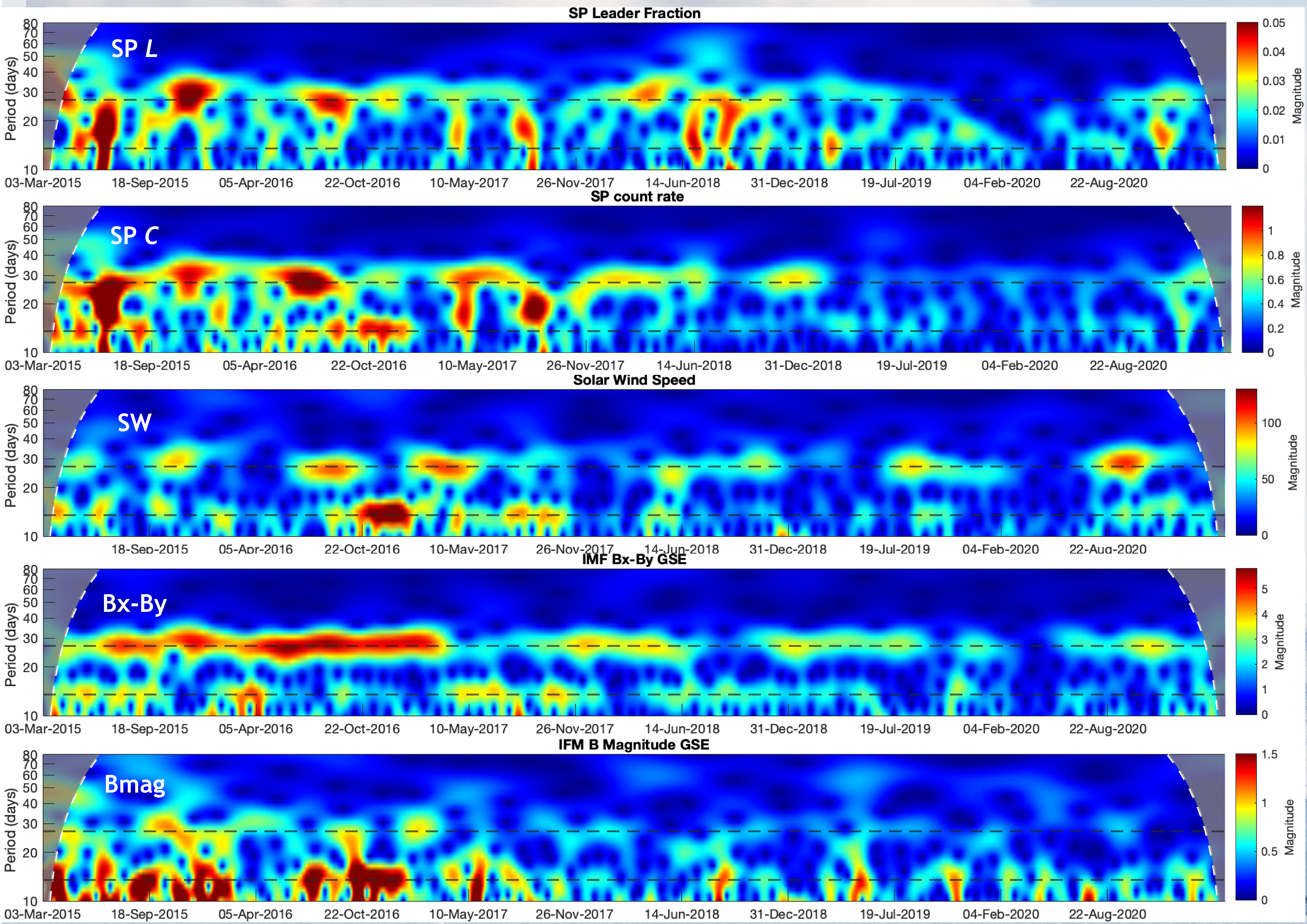


COMPARISON OF C AND L
FROM SP, JB, MC, AND MA STATIONS

Prepared by Pradiphat Muangha



Results of Wavelet Analysis



- C see:
  - two significant signal with periodicity of 27-day and 13-day
  - Mostly similar to solar wind
- L see:
  - correlated with C in 27-day periodic
  - but much weaker in periodic of 13-day.
- So, the spectral variation is only 27-day period not a harmonic

Prepared by Pradiphat Muangha

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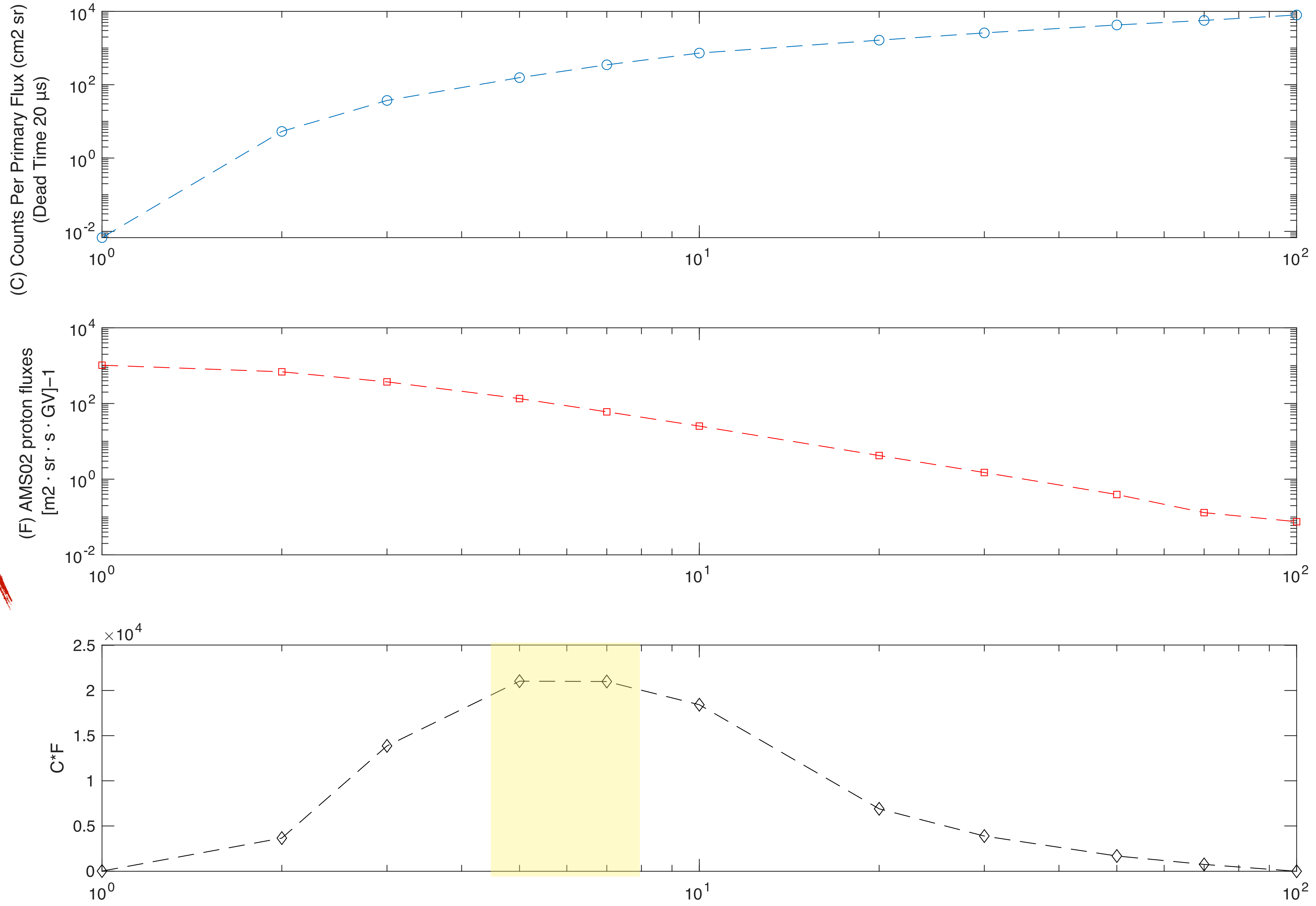
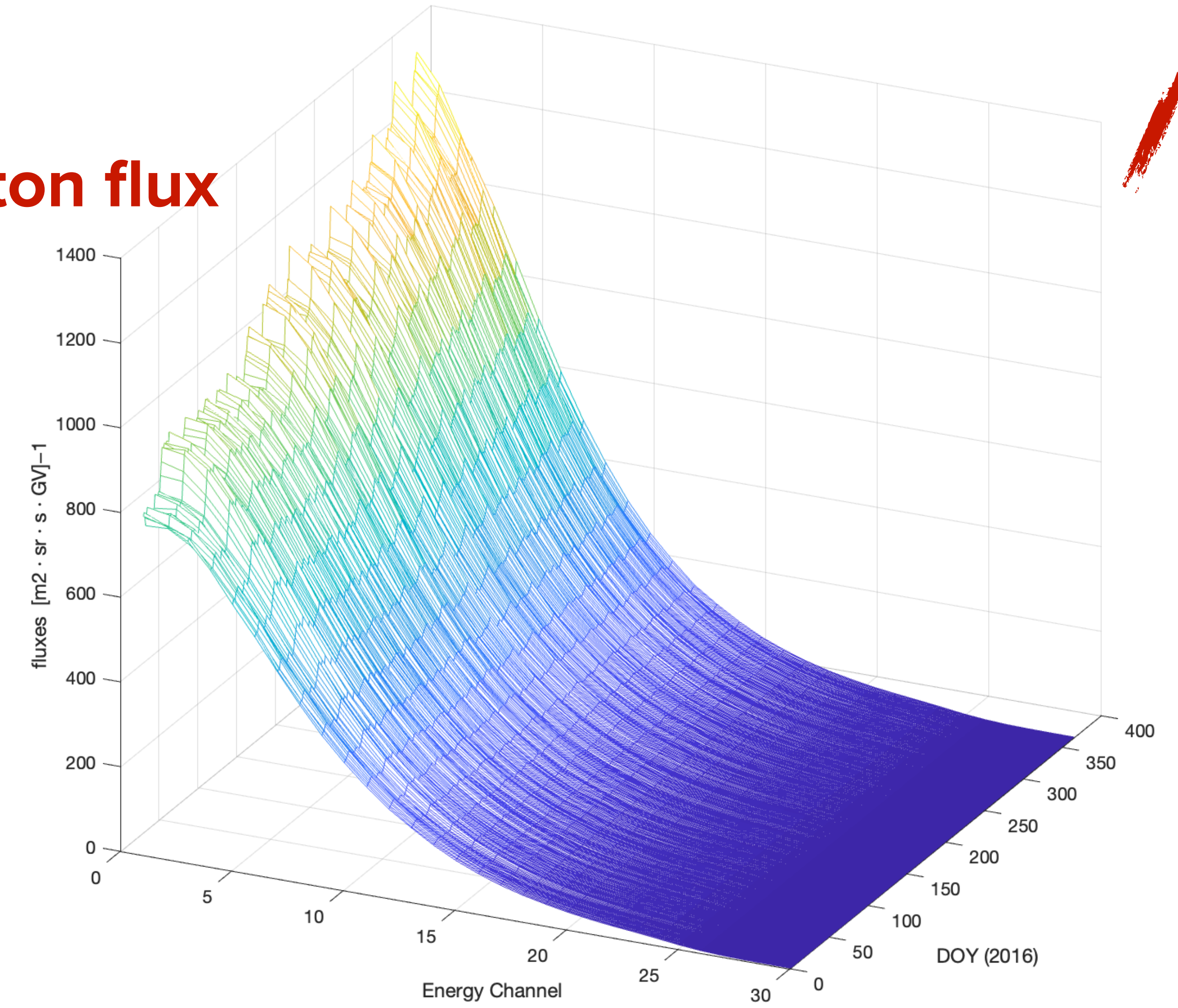
Table 3. Proton Yield Functions of a Standard 3NM64 at Sea Level for Various Electronic Dead Times

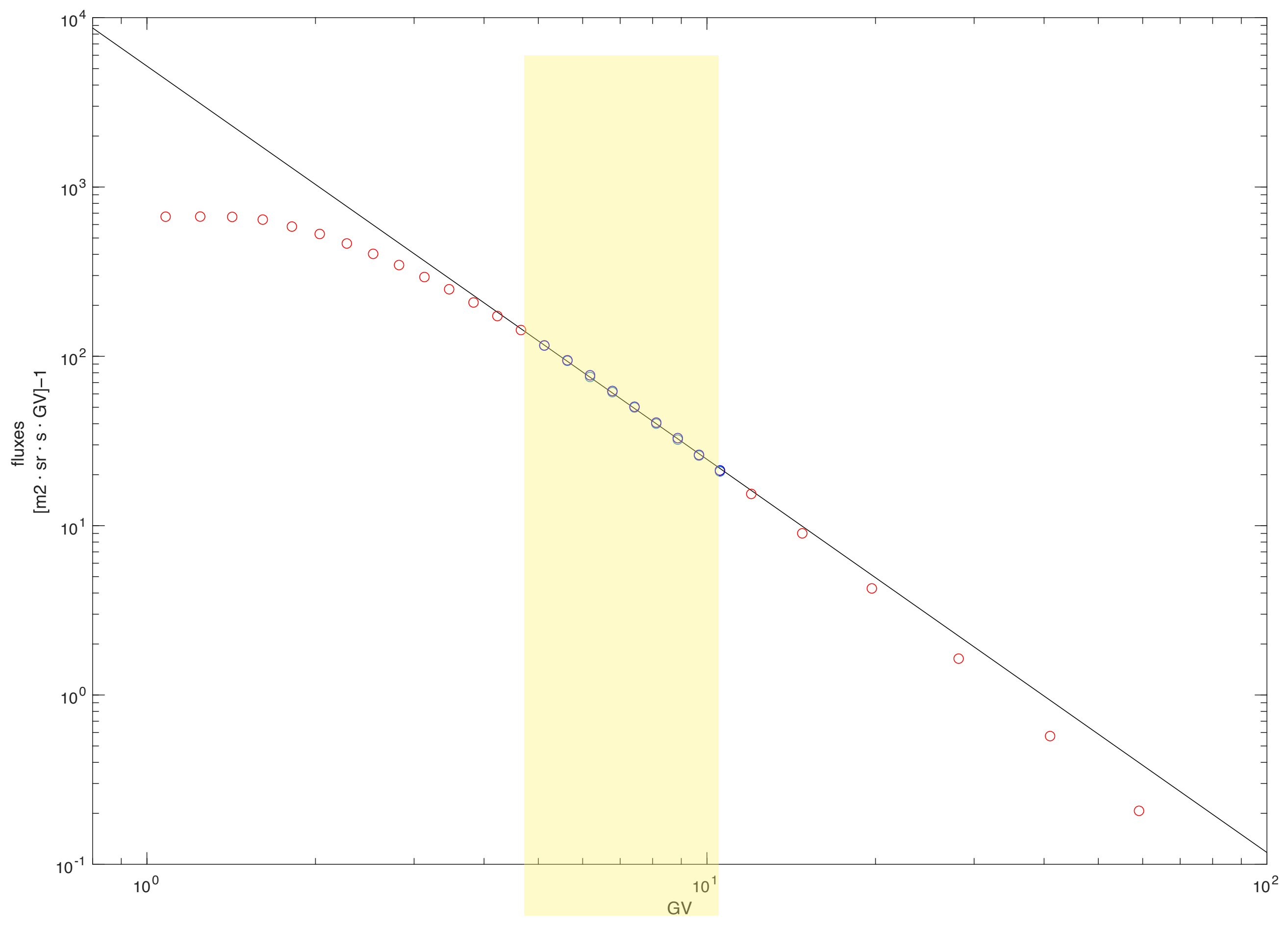
R (GV)	E_k/Nucleon (GeV)	Counts Per Primary Flux (cm² sr) Dead Time 0 s	20 μs	100 μs	1.2 ms	4 ms
0.5	0.1249	—	—	—	—	—
0.7	0.2324	1.34e−2	1.33e−2	1.30e−2	1.19e−2	1.18e−2
1	0.4331	3.65e−1	3.62e−1	3.52e−1	3.20e−1	3.18e−1
2	1.271	1.12e+1	1.10e+1	1.07e+1	9.60e+0	9.51e+0
3	2.205	4.26e+1	4.21e+1	4.06e+1	3.61e+1	3.57e+1
5	4.149	1.61e+2	1.59e+2	1.52e+2	1.33e+2	1.31e+2
7	6.125	2.38e+2	2.34e+2	2.24e+2	1.94e+2	1.91e+2
10	9.106	3.78e+2	3.72e+2	3.54e+2	3.05e+2	3.01e+2
20	19.08	8.59e+2	8.43e+2	7.99e+2	6.81e+2	6.71e+2
30	29.08	1.31e+3	1.28e+3	1.21e+3	1.03e+3	1.01e+3
50	49.07	2.18e+3	2.14e+3	2.01e+3	1.70e+3	1.67e+3
70	69.07	3.04e+3	2.97e+3	2.79e+3	2.34e+3	2.30e+3
100	99.07	4.23e+3	4.13e+3	3.87e+3	3.24e+3	3.19e+3
200	199.1	8.06e+3	7.83e+3	7.30e+3	6.06e+3	5.95e+3
300	299.1	1.18e+4	1.14e+4	1.06e+4	8.76e+3	8.59e+3
500	499.1	1.86e+4	1.80e+4	1.67e+4	1.38e+4	1.35e+4
700	699.1	2.53e+4	2.44e+4	2.26e+4	1.85e+4	1.81e+4
1000	999.1	3.73e+4	3.58e+4			

P.-S. Mangeard et al. 2016b



Averaged AMS02 proton flux





Prepared by Pradiphat Muangha

AMS-02 SPECTRUM VS LEADER FRACTION

Conclusions

- Using time-delay histograms from single NM station to calculate “leader fraction *L*” can be use to observe cosmic rays spectral variations.
- Comparative analysis of L for 4 Antarctic NM stations, SP, MC, JB, and MW, variation in L tracking with *C* very well.
- The 27-day variation in *L* was weaker than GCR count rate *C*
- The 27-day variation in *L* and *C* are significant correlated with solar wind speed but not with magnetic field magnitude
- Wavelet analysis results:
  - *C* are strong two significance signals with periodicity of 27-day and 13-day similar to solar wind speed.
  - *L* showed no visible periodicity at half of the solar rotation period. So, the spectral variation is only 27-day period, not a harmonic
- The 27-day variations of both C and L were strong during 2015-2016 but continuously weak during 2019-2020.